



**A University of Sussex DPhil thesis**

Available online via Sussex Research Online:

<http://sro.sussex.ac.uk/>

This thesis is protected by copyright which belongs to the author.

This thesis cannot be reproduced or quoted extensively from without first obtaining permission in writing from the Author

The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the Author

When referring to this work, full bibliographic details including the author, title, awarding institution and date of the thesis must be given

Please visit Sussex Research Online for more information and further details

**Synaesthesia, Hypnosis and Consciousness**

**Hazel Patricia Anderson**

**Submitted for the degree of  
Doctor of Philosophy in Psychology**

**School of Psychology**

**University of Sussex**

**May 2015**

**Declaration**

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Part of this thesis has however already been published as listed below:

Reported in chapter 2:

Anderson, H. P., Seth, A. K., Dienes, Z., & Ward, J. (2014). Can grapheme-color synesthesia be induced by hypnosis? *Frontiers in human neuroscience*, 8.220

Portions of this thesis were carried out in collaboration with others:

Reported in chapter 5: Dr Ryan Scott contributed to the design and programming of experiment 2A, 2B and 2C. The design, execution and reporting of all experiments was conducted by the author of this thesis and supervised by Prof Jamie Ward, Prof Zoltan Dienes and Prof Anil Seth.

**Signature**

## **Acknowledgements**

Thank you very much to Mr Jonathan Laredo and the Sackler Centre for Consciousness Science for funding the research. I would like to thank my supervisors who have guided me through my PhD, Jamie Ward, Zoltan Dienes and Anil Seth. Dr Ryan Scott also provided great guidance and technical assistance for experiment 2 in Chapter 5.

Other colleagues have shared their knowledge and experience which I am grateful to, in particular Nicolas Rothen, Clare Jonas, Maxine Sherman, Camilla During and Natalie Gould. Finally, thanks to my family, and in particular to Rebecca Grist who has kept me sane throughout this process.

**UNIVERSITY OF SUSSEX**

Hazel Anderson

Doctor of Philosophy in Psychology

**Synaesthesia, Hypnosis and Consciousness****Summary**

For people with synaesthesia, a percept or concept (inducer) triggers another experience (concurrent) which is usually in a different modality. The concurrent is automatic, and in the case of certain types of synaesthesia also consistent, however the relationship between the inducer and concurrent is not fully understood and shall be investigated in this thesis from different perspectives.

The first is using hypnosis to suggest synaesthesia-like phenomenological experiences to participants, and measuring behavioural responses to see whether they behave in a similar manner to developmental synaesthetes. Results from hypnotic; 1) grapheme-colour (GC) synaesthesia; 2) motion-sound synaesthesia; suggest that phenomenological experiences similar to developmental synaesthesia can be experienced by highly susceptible participants, but is not associated with the same behaviour as developmental synaesthetes.

Developmental GC synaesthetes were tested to determine whether a grapheme presented preconsciously binds with the concurrent colour to the extent that it influences behaviour or evokes the phenomenology of colour. Two techniques were

used, gaze-contingent substitution (GCS) and continuous flash suppression (CFS).

Using GCS, it was shown that although digits can be primed preconsciously, they don't bind with their concurrent colour to influence behaviour. Nevertheless, many synaesthetes still experienced colours though they didn't necessarily match the primed digit. CFS experiments showed that the colour of a grapheme's concurrent, or whether the grapheme is presented in the correct or incorrect colour for that synaesthete, doesn't influence the time for conscious perception of a grapheme, even though colour words presented in the correct colour are perceived faster than those in the wrong colour. Phenomenological differences were compared to the behavioural measures using questionnaires modified using factor analysis (the R-RSPA and R-ISEQ).

Overall, inducers must be seen consciously for them to bind with the concurrent, and experiencing the phenomenology of synaesthesia is not sufficient to behave like a synaesthete.

## Table of Contents

CHAPTER 1: .....	1
SYNAESTHESIA, HYPNOSIS AND CONSCIOUSNESS- OVERVIEW.....	1
1.1 Introductory remarks .....	1
1.2 Hypnosis.....	4
1.3 Hypnosis and synaesthesia .....	11
1.5 Synaesthesia, attention and consciousness.....	18
1.6 Synaesthesia and mental imagery .....	29
1.7 Overview of Papers .....	30
1.8 Discussion .....	39
CHAPTER 2: .....	44
CAN GRAPHEME-COLOUR SYANESTHESIA BE INDUCED BY HYPNOSIS?...44	
-PAPER 1 .....	44
2.1 Abstract .....	44
2.2. Introduction .....	46
2.3 Method .....	53
2.4 Results .....	58
2.5 Discussion .....	65
CHAPTER 3: .....	70
HYPNOTIC MOTION-SOUND SYNAESTHESIA AND MENTAL IMAGERY .....	70
-PAPER 2 .....	70
3.1 Abstract .....	70
3.2 Introduction .....	71
3.3 Method .....	76
3.4 Results .....	79
3.5 Discussion .....	92
CHAPTER 4 .....	96
PRINCIPLE COMPONENT ANALYSES OF QUESITONNAIRES MEASURING INDIVIDUAL DIFFERENCES IN SYNAESTHETIC PHENOMENONOLOGY .....	96
-PAPER 3 .....	96
4.1. Abstract .....	96
4.2. Introduction .....	97
4.3. Method .....	101
4.4 Results .....	103

4.5. Discussion .....	116
4.6. Appendix .....	120
CHAPTER 5 .....	126
GRAPHHEME-COLOUR SYNAESTHESIA REQUIRES CONSCIOUS AWARENESS FOR PERCEPT BINDING .....	126
-PAPER 4 .....	126
5.1 Abstract .....	126
5.2 Introduction .....	127
5.3 EXPERIMENT 1 .....	133
5.3.1 Experiment 1A .....	137
5.3.2 Experiment 1B .....	145
5.3.3 Experiment 1C .....	148
5.4 EXPERIMENT 2 .....	155
5.4.1 Experiment 2A .....	156
5.4.2 Experiment 2B .....	162
5.5.3 Experiment 2C. ....	167
5.6 Discussion .....	171
FINAL CONCLUSIONS OF THE THESIS .....	176



## List of Tables

**Table 2.1.** Summary of subjective colour experiences for each participant for the hypnosis condition only in descending order from the participant who experienced colour for the most trials to least. The table shows the percentage of trials where a colour was reported, average intensity (1 = no colour, 6 = vivid colour) and percentage of graphemes within the array perceived as coloured.

**Table 3.1.** Spearman's Rho correlations between behavioural measures for the experimental block (non-MS synaesthetes) ignoring group against post-experiment questionnaire responses.

**Table 4.1.**

Factor loadings and reliability analysis.

**Table 4.2.**

Factor loadings and reliability analysis.

**Table 4.3.**

Classifications of the synaesthetes.

**Table 4.4.**

Spearman's Rho correlations between; the projector and associator dimensions of the R-ISEQ and R-RSPA; the four dimensions of the CLaN questionnaire; the Synaesthesia Battery (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007) consistency measure.

**Table 5.1.** Spearman's Rho correlations between the reaction time (ms) and error (number) data and the CLaN and R-RSPA questionnaire dimensions for the synaesthetes.

**Table 5.2.** Spearman's Rho correlations between colour priming reaction times (ms) and error (number of) rates and the CLaN and R-RSPA for synaesthetes.

**Table 5.3.** Spearman's Rho correlations between accuracy, confidence, vividness and number of colours for synaesthete participants and the CLaN and R-RSPA measures.

**Table 5.4.** Spearman's Rho correlations between reaction times (ms) and error rates (number of) with the CLaN and R-RSPA questionnaires.

**Table 5.5.** Spearman's Rho correlations between the median reaction times (ms) and error rates of the behavioural data, and the CLaN and R-RSPA questionnaires.

## List of Figures

**Figure 1.1.** From Grossenbacher and Lovelace (2001). This diagram depicts alternative routes for concurrent activation from the inducer.

**Figure 1.2.** Example embedded-figure stimulus (A) and how it would look if completed coloured (B) or coloured more in line with synaesthete's phenomenological reports (C).

**Figure 2.1.** An example stimulus (A) as presented (in black font), (B) a schematic assuming presentation in colour, and (C) a partially coloured version in line of the phenomenological reports of projector synaesthetes. Note that stimuli were never presented in colour during the experiment.

**Figure 2.3.** Shape detection accuracy for control and hypnosis conditions across stimulus durations (1-4 seconds). Error bars represent 1 SEM.

**Figure 2.4.** The mean intensity of colours (1 = no colour, 6 = vivid colour) reported for trials in which the embedded figure was correctly or incorrectly detected dependent on whether the participant saw many colours or few colours. Error bars represent 1 SEM.

**Figure 2.5.** The percentage of graphemes within the array being reported as coloured for trials in which the embedded figure was correctly or incorrectly perceived. Error bars represent 1 SEM.

**Figure 2.6.** Shape detection accuracy for lots and little colour responders during the hypnosis condition across stimulus durations (1-4 seconds). Error bars represent 1 SEM.

**Figure 3.1.** Accuracy for auditory or visual trials at baseline, while ignoring group. Error bars represent +/- 1SEM.

**Figure 3.2.** Accuracy ( $d'$ ) of low, medium and high susceptibility participants and MS synaesthetes for visual and auditory trials in the baseline block.

**Figure 3.3.** Response bias of low, medium and high susceptibility participants and MS synaesthetes for visual and auditory trials in the baseline block. Error bars represent  $\pm$  1SEM.

**Figure 3.4.** Accuracy ( $d'$ ) change for low, medium and high susceptible groups. Error bars represent  $\pm$  1SEM.

**Figure 3.5.** Response bias change for low, medium and high susceptible participants for auditory and visual trials. Error bars represent  $\pm$  1SEM.

**Figure 3.6.** Percentage of visual trials which auditory beeps were heard for in low, medium and high susceptible participants. Error bars represent  $\pm$  1SEM.

**Figure 4.1.** Mean projector and associator scores for the revised questionnaires (R-ISEQ and R-RSPA).

**Figure 4.2.** Diagram of colour locus for graphemes.

**Figure 5.1.** Example gaze-contingent priming images. When fixation is roughly central, a prime is displayed at both the left and right. If gaze moves towards either side, the corresponding prime is removed leaving only the crowding visible. After presentation of the prime for 2500ms, the crowding only image is shown for 100ms.

**Figure 5.2.** Trial sequence for Experiment 1A. Due to shrinking of stimuli for the diagram, it is not possible to see the digits within the crowding.

**Figure 5.3.** Mean reaction times for synaesthete and control participants in the digit priming task, for both repetition priming and task priming comparisons. Error bars represent  $\pm$  1SEM.

**Figure 5.4.** Median error rates in the digit priming task for synaesthete and control participants, with both repetition priming and task priming comparisons. Error bars represent the interquartile range.

**Figure 5.5.** Trial sequence for Experiment 1B. Due to shrinking of stimuli for the diagram, it is not possible to see the digits within the crowding.

**Figure 5.6.** Mean reaction times for synaesthetic colour congruent and incongruent trials. Error bars represent  $\pm 1$ SEM.

**Figure 5.7.** Trial sequence for Experiment 1C. Due to shrinking of stimuli for the diagram, it is not possible to see the digits within the crowding.

**Figure 5.8.** Mean accuracy for low confidence and higher confidence trials for synaesthete and control participants. Error bars represent  $\pm 1$ SEM.

**Figure 5.9.** Median number of colour matches for the prime digit, chosen digit or neither. Error bars represent the interquartile range.

**Figure 5.10.** Example colour palette for a synaesthete, and how the graphemes were chosen for Experiments 2A and 2B of the CFS studies.

**Figure 5.11.** Experiment 2A set up and trial sequence.

**Figure 5.12.** Median reaction times for breakthrough for greyscale or colourful graphemes, in both synaesthetes and controls. Error bars represent interquartile range.

**Figure 5.13.** Mirror set up and trial sequence for Experiment 2B.

**Figure 5.14.** Median reaction times for congruent, incongruent and neutral trials for synaesthete and control participants. Error bars represent interquartile range.

**Figure 5.15.** Experiment 2C CFS set up.

**Figure 5.16.** Median reaction times for congruent, incongruent and neutral words. Error bars represent interquartile range.

**List of Abbreviations**

AFC-	Alternative Force Choice
CAIS-	Clarity of Auditory Imagery Scale
CCT-	Cascaded Cross-Tuning
CFS-	Continuous Flash Suppression
CLaN-	Coloured Letters and Numbers
DES-C-	Dissociative Experiences Scale-Comparison
EEG-	Electroencephalography
ERP-	Event Related Potential
FA-	Factor Analysis
fMRI-	functional Magnetic Resonance Imaging
GC-	Grapheme-Colour
GCC-	Gaze-Contingent Crowding
HOT-	Higher Order Thought
ISEQ-	Illustrated Synaesthetic Experience Questionnaire
KMO-	Keiser-Meyer-Olkin
MS-	Music-Sound
PCA-	Principle Component Analysis
PET-	Positron Emission Tomography
R-ISEQ Revised-	Illustrated Synaesthetic Experiences Questionnaire
R-ISPA-	Revised- Rouw and Scholte Projector Associator
RGB-	Red Green Blue
RSPA	Rouw and Scholte Projector-Associator
RT-	Reaction Time
VVIQ-	Vividness of Visual Imagery Questionnaire
VWFA-	Visual Word Form Area

## CHAPTER 1:

### SYNAESTHESIA, HYPNOSIS AND CONSCIOUSNESS- OVERVIEW

#### 1.1 Introductory remarks

##### 1.1.1 What is synaesthesia?

Synaesthesia is an experience where a percept or concept (inducer) triggers another experience (concurrent) which is usually in another modality (Grossenbacher & Lovelace, 2001). These pairings are not experienced by the majority of the population (Ward & Mattingley, 2006). A large range of synaesthesia types have been discovered, and each is named by the pairing of inducer and concurrent, in that order (Grossenbacher & Lovelace, 2001). One of the most common types is grapheme-colour (GC), which has a prevalence of roughly 1 % (Simner et al., 2006). For GC synaesthetes, a letter, digit or grammatical symbol triggers an automatic colour experience (Mattingley, Rich, Yelland, & Bradshaw, 2001) which is consistent over time (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993). Although there are some trends for the colour which is experienced for each grapheme, such as A is often red (Simner et al., 2005) in general, the colour and grapheme matching is idiosyncratic, each synaesthete has their own individual 'colour palette' (Hubbard & Ramachandran, 2003). New types of synaesthesia are constantly being discovered, such as motion-sound (MS) synaesthesia, where viewing motion or flashing lights causes a concurrent sound, which was first reported in 2008 and for which there is only one published study (Saenz & Koch, 2008). Synaesthesia is a fascinating experience which is connected to all senses, taste (Simner & Haywood, 2009; Ward & Simner, 2003), touch (Banissy, Cohen Kadosh, Maus, Walsh, & Ward, 2009; Banissy & Ward, 2007), sound (Ward,



Huckstep, & Tsakanikos, 2006), sight (Saenz & Koch, 2008; Simner et al., 2005) and smell (Cytowic, 1993).

### **1.1.2 Why research synaesthesia?**

Synaesthesia may be a rare and poorly understood experience, but most people with synaesthesia enjoy being a synaesthete. Many didn't know that it was unusual to experience the world as they do until accidentally finding out that others don't, for example, see music, or discover synaesthesia in the media. Rather than causing problems, memory advantages have been measured in some areas compared to non synaesthetes (Rothen, Meier, & Ward, 2012). If synaesthesia is not a problem, then why research it? Synaesthesia binds two different percepts or concepts, and allows exploration of how this binding occurs. Using synaesthesia as an example, we can test how percept binding occurs, what neural areas are involved in this integration, why particular percepts are bound and not others, or what cognitive mechanisms are required for this binding? Synaesthesia can be used to research the development of perception (Baron-Cohen, 1996; Spector & Maurer, 2009) or neural pruning during normal development (Cohen Kadosh, Henik, & Walsh, 2009). Enhanced memory abilities associated with synaesthesia (Rothen et al., 2012) give potential for the development of new memory improvement techniques. Percepts which are not 'real' but nonetheless experienced also enable research of internally generated perception. Apart from options to investigate perception more generally, there is the major question of how the inducer triggers the concurrent? Are these two percepts linked at a neuroanatomical level? Or can anyone experience synaesthesia? Does the inducer always trigger the concurrent, or are there limitations on the synaesthetic experience? There is therefore a wide array of processes which can be investigated in synaesthesia research, regarding normal and unusual development.

This thesis aimed at expanding our understanding of the conscious experience of synaesthesia from three perspectives. The first was to use hypnosis to create synaesthesia-like experiences in people who do not naturally experience synaesthesia. At the time of starting this thesis, there was only one published study that created synaesthesia in non synaesthetes using hypnosis (Cohen Kadosh, Henik, Catena, Walsh, & Fuentes, 2009). In Paper 1 and Paper 2 hypnosis was used to create synaesthesia-like experiences in non synaesthetes, and their behaviour was measured on tests previously conducted on real synaesthetes. The relationship between synaesthesia phenomenology and behaviour could therefore be tested in non synaesthetes.

The second direction was to explore the phenomenology of GC synaesthetes to better understand the variation in this particular type of synaesthesia. Existing phenomenology questionnaires were tested using factor analysis to find out how the sub types of GC synaesthesia are related to each other and to analyse the factorial validity and reliability of these commonly used questionnaires. This would allow better classification of synaesthetes and therefore more accurate grouping of participants in GC experiments.

Finally, whether a synaesthetic inducer can bind with its colour was researched using two techniques which allow a grapheme to be presented without conscious awareness. If the pre consciously viewed grapheme can bind with its concurrent, and influence behavioural responses, then it would be known that synaesthesia can occur without conscious awareness. Furthermore, by recording phenomenology, it could be determined whether the conscious experience of colour can occur without a consciously detected grapheme.

In this chapter, the literature on the possibilities for studying synaesthesia with hypnosis, the phenomenology of GC synaesthesia and the role of attention and consciousness in synaesthetic experience will be reviewed.

## **1.2 Hypnosis**

### **1.2.1 What is hypnosis?**

Defining hypnosis is difficult, as the theories of hypnosis are so varied that incorporating them into one working definition poses problems (Wagstaff, 2014). Therefore hypnosis is generally described in terms of the process rather than a definition. A hypnosis session usually consists of three sections. Initially, participants are asked to focus intently on something particular (e.g., on the back of the participant's hand) and brought into a relaxed state ready to partake in the hypnosis session and receive the suggestions given to them. This is the induction. The nominal "entering into hypnosis" is usually signalled by counting upwards to a number defined as being indicative of reaching hypnosis, before informing the participant that they are now hypnotised. There is however debate whether the induction used in hypnosis to create the hypnotic state is actually required for hypnosis, and comparison of the induction labelled as "relaxation" or "hypnosis" has found that it is the term hypnosis which increased the susceptibility of participants most, not the induction itself (Gandhi & Oakley, 2005). The main part of the hypnosis session involves making suggestions to the participant. The third and final section, bringing the participant back "out of hypnosis", usually is counting backwards down from the maximum number reached in the induction, back to one.

Instrumental hypnosis (using hypnosis as a tool to study other cognitive processes) can create transient symptoms similar to clinical populations, at least on the

surface, or unusual perceptual experiences. Cognitive processes can be manipulated in non-clinical participants and their impact measured (Oakley & Halligan, 2009). In this way, hypnosis might be a useable tool for studying synaesthetic processing in non synaesthetes, a question which will be asked in this thesis. In comparison, intrinsic hypnosis research investigates the nature of hypnosis itself.

### **1.2.2 Types of suggestions**

Suggestion types can be roughly divided into motor suggestions (movements) or cognitive suggestions (e.g. alterations of perception). A positive suggestion adds something, such as making somebody's hands move together or hallucinate a sound. Negative suggestions remove something, like preventing someone from lifting their arm, or not being able to see. Motor suggestions are often accompanied by perceived lack of control (Oakley & Halligan, 2009).

A suggestion is first given, followed possibly by some preparation time, and then finally the suggestion is either experienced or tested. An example would be giving a suggestion for an arm to become stiff so that it can't bend (Bowers, 1998). Initially, the participant would be asked to raise their arm out in front of them (preparation for suggestion) and be told that it is very stiff like a board so that it can't bend (suggestion) before being asked to try and bend it if they can (testing the suggestion). If the participant does not bend their arm, then they have passed the hypnotic suggestion. Suggestions which are tested before being brought "out of hypnosis" are hypnotic suggestions, those given but not tested until after being brought out of hypnosis are post-hypnotic suggestions. Post-hypnotic suggestions are usually triggered, such as by a clap of the hands.

Of greatest interest for this thesis, are cognitive suggestions which can create hallucinations similar to synaesthetic experiences. Auditory hallucination to hear the song 'Jingle Bells' is included in the Waterloo-Stanford group scale of hypnotic susceptibility, form C (Bowers, 1998). Hypnotic auditory hallucinations and real sound activate part of the right anterior cingulate which is not active during imagined sound (Ahmias, 1998) further supporting the ability for high susceptible people to experience auditory suggestions. If auditory hallucinations can be triggered by specific stimuli, this provides an opportunity to create auditory concurrents and synaesthesia-like experiences.

Visual hallucinations may seem harder to imagine for most people. Although one can imagine an image in their mind's eye, this is not altering the perception of an external visual stimulus as in GC synaesthesia. High susceptible participants (people who experience a range of hypnotic suggestions) have however been able to either add colour to a grey scale image, or drain colour from a coloured image (Kosslyn, Thompson, Costantini-ferrando, & Spiegel, 2000). This also corresponded to changes in activation in colour sensitive areas of the brain measured using positron emission tomography (PET). This showed an impressive ability to hypnotically change the perception of an external stimulus, however high susceptible participants can perform the add or drain colour task without hypnotic suggestion (McGeown et al., 2012). Suggestibility, rather than hypnosis, accounted for the changes in perception and activation measured using functional magnetic resonance imaging (fMRI). High suggestible participants do not automatically 'slip into' hypnosis when asked to perform colour alterations out of hypnosis (Mazzoni et al., 2009) however mental imagery abilities were not reported. The link between suggestibility and mental imagery is

unclear, nevertheless, colour perception can be manipulated by high susceptible participants and used as a tool in synaesthesia research.

### **1.2.3 Individual differences in hypnotic susceptibility**

Susceptibility (also called suggestibility) to hypnosis follows a normal distribution, with only a minority of people being responsive to many or few suggestions, and the majority being responsive to some (Kihlstrom, 2013). This grouping of participants labels them as low (few responses), medium (some responses) or high (many responses) susceptibility. There is variability in how participants are grouped depending on which screening measure of susceptibility used (Barnes, Lynn, & Pekala, 2009). The scale used in this thesis is the Waterloo-Stanford group scale of hypnotic susceptibility, form C (Bowers, 1998). Using a 12 point scale, low would be 0-3, medium 4-8, high 9-12 (Piccione, Hilgard, & Zimbardo, 1989) corresponding to 26.0% as low, 62.6% as medium and 11.4% as high susceptibility (Bowers, 1998). Motor suggestions, such as arm rigidity, are experienced by far more people (40-50%) than cognitive suggestions, such as a fly hallucination (16-23%) which are harder to evoke in participants (Barnes et al., 2009). Participants are therefore usually screened before taking part in hypnosis research so that participants of particular susceptibilities can be recruited. Susceptibility does however remain stable over 25 years (Piccione et al., 1989).

Mental imagery is the ability to deliberately experience internally generated percepts, such as imagining the sounds of a bell, visualising a tree in the mind's eye, or tasting a raspberry (Kosslyn, Behrmann, & Jeannerod, 1995). Hypnotic susceptibility is positively related to mental imagery (Glisky, Tataryn, & Kihlstrom, 1995) therefore to prevent confounds of mental imagery ability within hypnosis research, studies which involve positive hallucinations should record abilities across participant groups. No

personality traits have consistently correlated with hypnotic susceptibility (Nordenstrom, Council, & Meier, 2002).

#### **1.2.4 Theories of hypnosis**

There are many theories of hypnosis, each with its opposing counterpart. These can be grouped as state/ non-state, neurocognitive/ sociocognitive, or special process/ social-psychological (Hasegawa & Jamieson, 2002).

The state theory (or special process) theory is that hypnotic behaviour is actually different to non-hypnotic behaviour, insofar as people are able to perform or experience suggestions whilst hypnotised that they wouldn't be able to do without hypnosis (Spanos, 1986). The "hypnotic state" is required. Dissociation theory is a type of special process theory and proposes a dissociative process is required. Dissociation theory suggests these apparent new abilities are due to a dissociation of cognitive processing mechanisms (Hilgard, 1986; Woody & Bowers, 1994). Dissociation is either a sense of detachment, in respect to oneself or your environment, or compartmentalisation, where there is an impairment in a usually controllable process (Holmes et al., 2005). The state and special process theories are similar in that a change is required in the person for them to respond to the hypnotic suggestions. Some examples of proposed special abilities gained by participants through hypnosis are a reduction in perceived pain (Freeman, Barabasz, Barabasz, & Warner, 2000) or control over automatic colour word and font colour binding in the Stroop task (Raz, Moreno-Iñiguez, Martin, & Zhu, 2007). In order to test dissociation theories of hypnosis, variability in dissociation has been researched. Although correlational analysis between susceptibility and dissociation found no relationship between these (Dienes et al., 2009) this may be due to sub groups

within high susceptible people, one of which does experience dissociation (Terhune & Cardeña, 2010). Furthermore, even low dissociative high susceptible participants experience increased dissociation whilst hypnotised (Terhune, Cardeña, & Lindgren, 2011). Together, the evidence for a link between hypnotisability and dissociation is inconsistent, but needs to be considered in hypnosis research.

The non-state (or social-psychological) theory hypothesises that no new abilities are created by the hypnosis, the participant retains actual control of their action and chooses to respond in the way requested by the experimenter (Spanos, 1986). Variations in behavioural traits are compared to susceptibility to account for the range in response rate such as absorption (Rainville, Hofbauer, Bushnell, Duncan, & Price, 2002), mental imagery (Coe, St Jean, & Burger, 1980), fantasy proneness (Rhue & Lynn, 1989), compliance (Mazzoni et al., 2009; Raz, Kirsch, Pollard, & Nitkin-Kaner, 2006), and expectation (Gandhi & Oakley, 2005; Kirsch, 1985).

Neurocognitive research has been incorporated into cognitive theories of hypnosis, with neuroimaging investigation being used as evidence that hypnosis involves more than just imagining the experience (Oakley & Halligan, 2009). Differences in regions such as the frontal lobe (Egner, Jamieson, & Gruzelier, 2005; Farvolden & Woody, 2004; Gruzelier, 2006), anterior cingulate cortex (Rainville et al., 2002) or hemispheric asymmetry (Naish, 2010) have been measured. Neuroimaging techniques are also used to measure differences between hypnotic and resting states (Horton, Crawford, Harrington, & Downs, 2004; Maquet, Faymonville, & Degueldre, 1999; Terhune et al., 2011). Although differences are measured, it isn't clear exactly how they are related to susceptibility or how they change as a result of hypnosis.



The sociocognitive perspective is that hypnosis is goal directed, the participant acts dependent on their aims, expectations and opinions in order to control their thoughts and behaviour (Lynn & Green, 2011) even though they don't experience volition, it feels automatic and out of their control (Dienes & Perner, 2007). This is comparable to Hilgard's neo-dissociation theory where responding is goal directed and only feels out of control, this process being described as divided consciousness (Hilgard, 1986).

Another group of theories which are centred around conscious are higher order thought (HOT) theories which suggest that awareness of one's mental states is required for consciousness (Lau & Rosenthal, 2011). If someone sat down, they could think "I am sitting down". If they considered this action from a higher level first, "I am intending to sit down" then this would be a HOT. Cold control theory suggests hypnotic involuntariness is caused by performing an action without having the associated accurate HOT (Dienes & Perner, 2007). A person could lift their arm in response to a levity motor suggestion, but not have the associated HOT "I am intending to lift my arm" producing a feeling of loss of control over their actions.

More recently, there have been attempts to integrate different theories to reduce the dichotomy of competing theories (Raz & Shapiro, 2002), for example treating biological and psychological aspects separately confounds their general integration (Hasegawa & Jamieson, 2002). Integrating the theories is a promising step into explaining susceptibility and changes as a response to hypnosis, but has not yet been achieved.

### **1.3 Hypnosis and synaesthesia**

#### **1.3.1 Previous hypnotic synaesthesia research**

Hypnosis has been used to investigate synaesthesia in order to determine whether synaesthesia is due to neuroanatomical or functional differences. Initially, Cohen Kadosh and colleagues suggested to four high susceptible participants that the numbers 1-6 would each evoke a specific visual colour associated to it. Digits were then presented in black font against a coloured background which was either the same colour as that hypnotically suggested to the participant (congruent) or a different colour (incongruent). Participants had to indicate if a grapheme was present on the background. They showed that participants were less accurate at indicating a grapheme's presence when it was displayed against a congruent opposed to incongruent background. This was given as evidence of the automatic generation of the colour through post-hypnotic suggestion, its comparability with developmental synaesthesia, and that synaesthesia can be created without changes in neuroanatomy. Although interference effects were recorded, the interference itself was dramatically large, especially as the response of the only developmental synaesthete to be tested using a similar task was far less (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002). Further to this, the task the developmental synaesthete completed was far more difficult, having to indicate the grid reference of a particular grapheme rather than simply indicate if a grapheme was present. It is therefore surprising that such large interference effects were created through hypnosis.

The large interference effects could potentially be due to demand characteristics. Demand characteristics occur when a participant performs as they think the experimenter wishes them to, for example, they will 'hold back' on good performance or try harder in certain conditions (Orne, 1962; Spanos, 1986). As this may happen unconsciously, the participants may have performed poorer for congruent trials as they

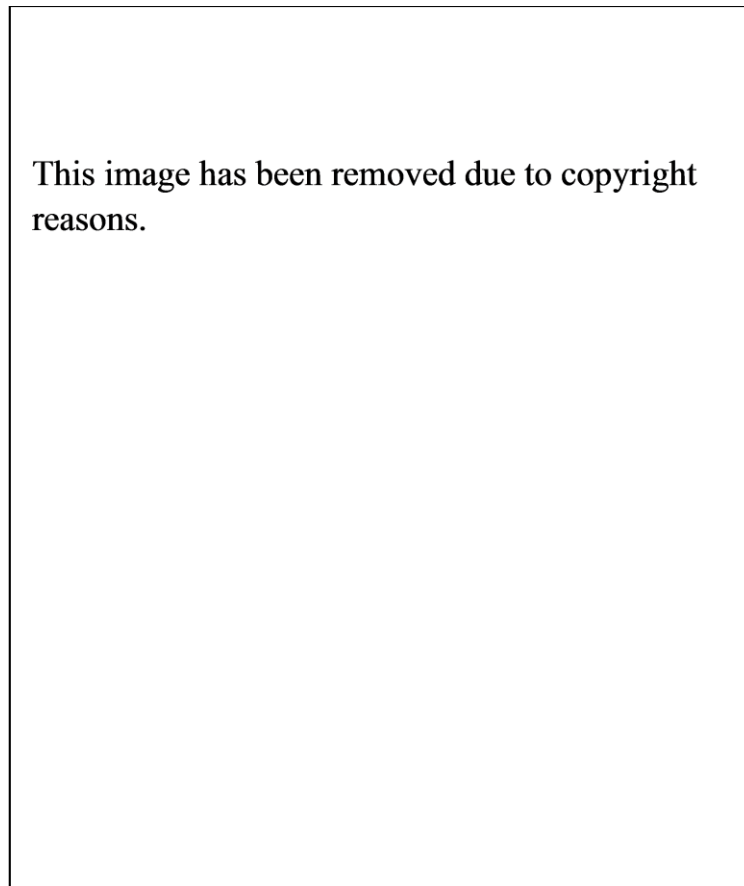
expected they should. In order to test whether hypnotic synaesthesia is comparable to developmental synaesthesia, demand characteristics would need to be controlled for, and an *improvement* in performance be looked for rather than an *impairment*. This is because it is easier to deliberately perform poorer than it is to perform better on a task. Also, as the phenomenology of the participants was not recorded in great detail by Cohen Kadosh et al. (2009), this would need to be known so that pure associations without colour phenomenology can be ruled out.

Furthermore, hypnotic synaesthesia can help with researching what the processes underlying hypnosis itself are (the intrinsic study of hypnosis). Theories of hypnosis can be roughly divided into those which posit hypnosis gives the subject new extra abilities that are not possible without hypnosis (such as reducing the perception of pain (Freeman et al., 2000)), and those which state hypnosis can't create new skills (eg., Spanos, 1986). If the performance of high susceptible people improves on a task due to synaesthesia-like hallucinations so that they behave like a developmental synaesthete, it would provide evidence that hypnosis can create new abilities. If not, it suggests that no new ability has been created.

## **1.4 Grapheme-colour synaesthesia phenomenology**

### **1.4.1 Theories of grapheme-colour synaesthesia**

There are many theories of GC synaesthesia, including both cognitive and neurological mechanisms. Here, some of these theories will be discussed briefly.



**Figure 1.1.** From Grossenbacher and Lovelace (2001). This diagram depicts alternative routes for concurrent activation from the inducer.

The disinhibited feedback model suggests that feedforward activation, which has travelled through an area which integrates information from multiple pathways, then feeds back through another pathway due to insufficient disinhibition (Grossenbacher & Lovelace, 2001). By this model, synaesthesia is caused by activation due to the inducer feeding back to the concurrent neural areas due to disinhibited feedback, as seen in Figure 1. The cross activation hypothesis posits that, using GC synaesthesia as an example, extra neural connections are required between the grapheme and colour areas of the brain (Ramachandran & Hubbard, 2001), more precisely the visual word form area (VWFA) and colour area (V4) which are adjacent in the fusiform gyrus and may be

connected (Hubbard, Brang, & Ramachandran, 2011). The proximity of these regions, and the heritability of GC synaesthesia (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996) led them to theorise cross-activation (depicted as horizontal activation in Figure 1) occurred between these areas, causing the GC synaesthesia. By this account, activation should pass directly from the inducer cortical area to the concurrent cortical area. Increased activation in areas associated with colour processing in response to graphemes by GC synaesthetes has been given as evidence for the cross-activation model (Hubbard, Arman, Ramachandran, & Boynton, 2005).

The re-entrant model, a variation on the cross-activation model, suggests that higher level grapheme processing feeds back to both the grapheme and colour areas (which are specifically linked for GC synaesthesia) (Smilek, Dixon, Cudahy, & Merikle, 2001). The cross-activation model has recently been modified to include many features of the other models, becoming a lot more all-encompassing including both excitation and inhibition, cross-activation between areas, bottom up and top down processes, to form the cascaded cross-tuning (CCT) model (Hubbard et al., 2011). This modification was in part due to advances in understanding of letter processing, suggesting it is a hierarchical process of feature detection and competition between letters (Dehaene, Cohen, Sigman, & Vinckier, 2005).

So why are these areas connected in the first place? One explanation is that everyone starts out as a synaesthete, and that through the normal pruning process these extra connections are removed, but that for some individuals they remain (Spector & Maurer, 2009). This would explain why synaesthesia runs in families, though not necessarily the same type (Barnett, Finucane, et al., 2008) and suggests that mutations in genes which control broader connectivity may account for synaesthesia (Bargary &

Mitchell, 2008). Research on genetic linkages to synaesthesia have already found promising results in coloured sequence synaesthesia (Tomson et al., 2011).

Alternatively, synaesthesia may be purely functional without neuroanatomical differences. This view is supported by temporary synaesthetic type experiences which can be triggered by hallucinatory drugs (Luke, Friday, & Terhune, 2012) or hypnosis (Cohen Kadosh, Henik, Catena, et al., 2009). In this thesis, whether special neuroanatomy is required for synaesthesia will be tested using hypnosis.

#### **1.4.2 Defining projector and associator grapheme-colour synaesthesia sub types**

GC synaesthetes experience colours for letters, digits and grammatical symbols and although there is large variability in how they experience the colours, the phenomenology of their GC synaesthesia. Not only does each synaesthete have their own colour palette (Simner et al., 2005) for the digits they experience colour for, but they may not have an associated colour for every grapheme, it may only be a subset of, say the numbers 0-9. Although colour is the primary reported characteristic of the phenomenology, other properties are also reported, such as texture (Eagleman & Goodale, 2009). Furthermore, they can experience the colours in different places. Projector GC synaesthetes see the colour either directly on the grapheme itself, whereas associator GC synaesthetes see the colour in their minds eye, or have more a sense of ‘knowing’ or ‘feeling’ that a grapheme is a certain colour (Ward, Li, Salih, & Sagiv, 2007). In order to corroborate this distinction, questionnaires have been designed to measure which sub type of GC synaesthesia a person has, and studies have looked for behavioural differences between the groups.

### **1.4.3 Grapheme-colour synaesthesia phenomenology measures**

The two main GC sub type questionnaires are the Illustrated Synaesthetic Experience Questionnaire (ISEQ; Skelton, Ludwig, & Mohr, 2009) and the Projector Associator (RSPA; Rouw & Scholte, 2007) questionnaire. The ISEQ contains a cartoon picture of a person viewing black graphemes on a piece of paper, and five statements, each with a picture to illustrate the phenomenology of that question visually (such as coloured letters in the mind's eye). A seven point Likert scale is used (1 = least accurate, 7 = most accurate). To determine which type a synaesthete is, the mean of the three associator questions is subtracted from the mean of the two projector questions. A value of 1 or greater indicates a projector, less than 1 an associator, and around zero is undetermined. The RSPA contains 12 questions, answered using a five point Likert scale (1 = strongly disagree, 5 = strongly agree). Classification is again done by subtracting the mean associator from projector value (six questions of each sub factor). Positive values indicate a projector, negative an associator. There are limitations with both questionnaires, they both presume that colour phenomenology lies on a continuum with projector and associator being at either end of this bimodal distribution. Skelton and colleagues mention that two of their synaesthetes agreed with both projector and associator statements and labelled them as 'undetermined'. Each questionnaire was also made with a very limited sample size, 12 for the ISEQ and 18 for the RSPA, which appears limited when attempting to investigate variability in phenomenology. Further, neither questionnaire has been through the usual method of validation for a new measure, factor analysis, which allows underlying factors to be grouped. In this thesis, the ISEQ and RSPA will therefore undergo factor analysis using a far larger sample to determine whether projector and associator phenomenology is indeed a continuum, and if the questionnaires themselves are internally valid and reliable.

#### **1.4.4 Behavioural differences between projectors and associators**

What, if any, behavioural differences have been measured between these groups? A clear distinction has been measured using a synaesthetic Stroop task. Participants had to say out loud into a microphone, either the real colour or their synaesthetic colour, of graphemes presented in either a congruent or incongruent colour for that participant (Dixon, Smilek, & Merikle, 2004). Projectors were faster at naming their synaesthetic colour and associators faster for naming font colours. This double dissociation was given as evidence for the higher/ lower distinction of GC synaesthesia. Lower synaesthetes are those for whom the features of the graphemes trigger the colour, whereas for higher synaesthetes it is the concept of the number which has the colour experience (Ramachandran & Hubbard, 2001). The behavioural distinction between projectors and associators has been replicated (Ward et al., 2007) although exploration of linkages between higher characteristics and colours (dice patterns, number words, spatial forms and time) found no pattern between projectors and lower characteristics, or associators and higher characteristics. Ramachandran and Hubbard (2005) suggested tentatively when they conducted fMRI investigation of GC synaesthesia that projector (or lower) synaesthesia results from ventral pathway cross activation, and more parietal areas for associator (or higher) synaesthesia. The distinction has been further supported by increased inferior temporal connectivity in projectors (Rouw & Scholte, 2007), and grey matter differences between projectors (perceptual areas) and associators (memory areas) (Rouw & Scholte, 2010) although this doesn't paint a completely clear picture.

According to the CCT model of synaesthesia and the hierarchical network of letter detection, there should be an association between the similarity of features within a letter and the colour it evokes (Brang, Rouw, Ramachandran, & Coulson, 2011). Correlational analysis supported a relationship between letter shape and colour



similarity for both projectors and associators. Critically, this effect was significantly larger for projectors than associators, supporting the greater role of lower level feature analysis in projector synaesthetes (Brang et al., 2011).

## **1.5 Synaesthesia, attention and consciousness**

### **1.5.1 Synaesthetic Stroop task**

Originally in the field of synaesthesia research, emphasis was put on measuring behavioural differences between synaesthetes and non synaesthetes to demonstrate that the phenomenon is genuine (Ward et al., 2007). In the Stroop task (Stroop, 1935) participants state out loud the font colour of colour words presented in the correct colour (eg. RED written in red ink) or incorrect colour (eg. RED written in green). When the colour and word don't match RTs are longer and more errors are made, this is due to interference from the automatically read colour word. This task can be modified for a wide array of synaesthesia types. Here the stimulus is paired with either the correct (congruent) or an incorrect (incongruent) concurrent. If interference effects are measured for incongruent trials, then it can be shown that the concurrent is automatically paired with the inducer and actually experienced by the synaesthete. A variety of synaesthetic Stroop tasks have been performed, confirming the automatic binding and therefore the genuineness of synaesthesia (Dixon et al., 2004; Mattingley et al., 2001; Mattingley, Payne, & Rich, 2006; Rothen, Nikolić, et al., 2013). Although this pairing, or 'binding' is automatic and consistent, the relationship between measured behavioural differences and the phenomenology of the synaesthetic experience is less well understood. Furthermore, it doesn't demonstrate the level at which the colour is being linked with the grapheme, as colour associations rather than real colours can also cause interference in the Stroop task (Meier & Rothen, 2009).

Studying synaesthetes is not only informative for the field of synaesthesia, it also helps us understand conscious perception in non-synaesthetes. As synaesthesia is an unusual perceptual experience, what are the differences between synaesthetes and non synaesthetes which cause the generation of such experiences? Can anyone have similar experiences under certain conditions? As there is a large range of synaesthesia inducer and concurrent pairings we can test theories for a variety of percepts, and furthermore test the individual differences of conscious experience within each of them (Sagiv & Frith, 2013). For example, what causes the differences between projector and associator synaesthetes, and are these differences common to the general non-synaesthete population? From a personal perspective, synaesthesia is also a great opportunity to research unusual perceptual experiences which are actually enjoyed by the majority of people who experience them.

### **1.5.2 Visual search tasks**

A question of interest in GC synaesthesia, is whether when looking at a page of black font text, each grapheme in view is coloured, or only those being attended to? As binding of a grapheme and its concurrent colour is automatic (Mattingley et al., 2001), attention levels can be manipulated to see whether the same behaviour occurs across levels and therefore a grapheme and colour are binding without attention.

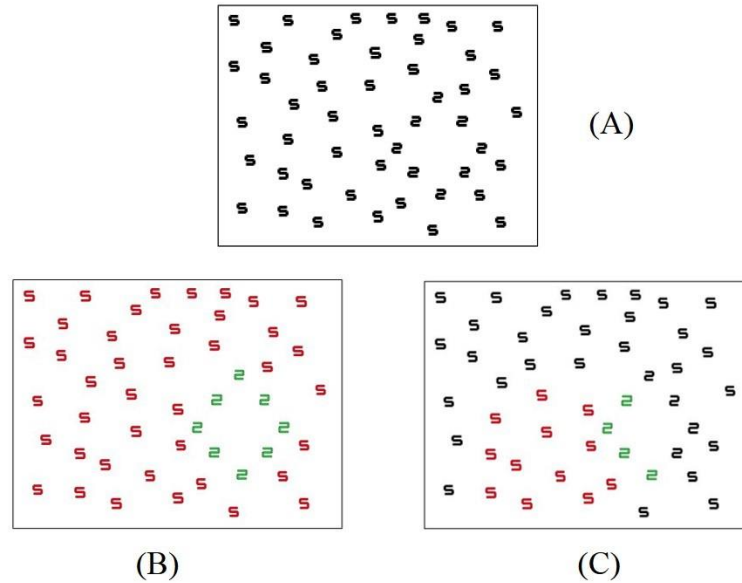
Several types of visual search tasks have been conducted, which are based on the principle that if elements within the visual array are coloured differently, this aids in the detection of a target (Hubbard, Arman, Ramachandran, & Boynton, 2005). If a colour binds with a grapheme pre attentively, it should aid in visual search. The first projector to be tested using a visual search task was participant C, who had to locate one of two possible target graphemes presented against a background either congruent or

incongruent with the grapheme's concurrent, within an array of 7, 13 or 19 graphemes and then give its grid location on an imaginary 6 by 6 matrix (Smilek et al., 2001). C was slower at localising a grapheme when the background colour was congruent with the photism of the grapheme to be located although there was no difference between congruent and incongruent trial error rates. In a variation of this task synaesthete AD had to indicate which letter was presented (for 65 ms followed by a 100ms mask) on a green or red background (the colours for the two letters included, F and R) (Sagiv, Heer, & Robertson, 2006). Her RTs for trials when the grapheme and background colour were congruent were actually faster than those for incongruent backgrounds, the direct opposite pattern measured in C (Smilek et al., 2001). Phenomenological differences are suggested to account for this (Sagiv et al., 2006) and varieties of phenomenology will be discussed later in this chapter.

Synaesthete WO completed a similar task, having to detect a 2 within an array of 5's, or an 8 within 6's (Palmeri et al., 2002). The font style was digitised, the numbers were made of straight lines only and as such there was minimal difference in local properties. For WO, both 8 and 6 are blue and his RTs for responses (whether a target 8 or 2 was present or not) were similar as those for the controls, but for 2's (which are orange) he was faster than controls for detecting it against the 5's (which are green for him). WO stated that the 2 would "pop-out" from the colour, however when the distractors were nonsense symbols, this advantage ceased. The authors concluded that attention was required for the grapheme to bind with the colour, allowing distractor graphemes to be identified more easily and rejected. Two GC synaesthetes (AD and CP) had to detect the presence or absence of an individual grapheme target (the letter L) either upright or inverted (note the inverted L is a nonsense symbol), and surrounded by T's rotated at 180° (Sagiv et al., 2006). For synaesthetes all font was black, for controls

the inverted condition was black and the upright version had the L in colour (green or orange-mustard) as these were the synaesthete's concurrent colours for L. A marked RT difference between controls viewing real colour and synaesthetes showed that the colour was only added after identification of the grapheme, rather than aiding in detection of it. Together, these studies suggest that graphemes can appear coloured to GC synaesthetes, but that colour is secondary to grapheme identification. Inconsistent results required more detailed analysis, which has since been conducted.

To investigate whether colours aid detection of larger more complex grapheme arrays, an embedded-figures test was conducted where a shape made up of 6-8 graphemes which elicit the colour red, green, blue or yellow was embedded within an array of distractor graphemes (for example a diamond of 'E's which elicit red, surrounded by 'O's which trigger blue, and 'H's which trigger green) (Hubbard et al., 2005; Hubbard & Ramachandran, 2005; Ramachandran & Hubbard, 2001). Six synaesthetes and 120 control subjects completed this with all graphemes presented in black font and a further 120 control participants completed it in real colour (20 participants per synaesthete completed it in the photism colours). The accuracy of synaesthetes was significantly better than controls who viewed the array in black, but significantly worse than those who viewed it in real colour. Colours therefore bound to the graphemes, but not with the efficiency of real colour. Little detail of phenomenology was given which would strengthen understanding of the attention and colour relationship.



**Figure 1.2.** Example embedded-figure stimulus (A) and how it would look if completely coloured (B) or coloured more in line with synaesthetes phenomenological reports (C).

The most extensive embedded figures task study had a larger sample size (36 synaesthetes and 36 controls) and also recorded the percentage of graphemes in the array which were perceived as coloured and the vividness of any colour perceived (1= no colour, 6 = very vivid colour) (Ward, Jonas, Dienes, & Seth, 2010). Shapes (square, rectangle, diamond or triangle) and distractors were made of black mirror image 2's and 5's (similar to the Plameri et al. (2002) study). Figure 2 shows an example stimulus from this study and how it would look if it were completely, or partially, coloured. Ward and colleagues found synaesthetes to be significantly more accurate than control participants. Furthermore, they explored differences between projectors and associators, finding that although projectors reported experiencing colour on significantly more trials than associators, there was no significant difference in accuracy, percentage of

coloured digits within the array, or vividness of colour. The authors suggest that the colours helped in perceptual grouping of the graphemes, which aided in the detection of the embedded shape. This is in line with a perceptual grouping task conducted on two synaesthetes, where participants had to indicate which direction the graphemes within the display appeared to group (horizontal or vertical) (Ramachandran & Hubbard, 2001). The grapheme arrays were designed such that they could be grouped in terms of the shape of the graphemes themselves, or theoretically for the synaesthetes, in the opposite direction which matched their synaesthetic concurrent. The synaesthetes chose the direction corresponding to their colours whereas controls were more influenced by the graphemes. Visual search and grapheme direction is therefore influenced by perceptual grouping.

Serial visual search tasks although producing measurable differences between synaesthetes and controls in some studies, have not in every variation (Edquist, Rich, Brinkman, & Mattingley, 2006; Gheri & Baldassi, 2008). Together, these tasks demonstrate that synaesthetic colours can aid in perceptual grouping in ways similar to real colour, even though the strength of synaesthetic photisms are not necessarily as strong as real colour.

### **1.5.3 Visual crowding**

To suppress the conscious awareness of a stimulus, crowding can be used. A stimulus is surrounded by visually similar flanking elements: ‘distractors’. When viewed peripherally, the central stimulus is summated with the crowding distractors (Faivre, Berthet, & Kouider, 2012), suppressing it from conscious perception. If a grapheme is crowded by another four graphemes to form a cross shape, identification of the central grapheme is improved if it is presented in a different colour to the crowding graphemes

(Kooi, Toet, Tripathy, & Levi, 1994). Hubbard and Ramachandran (2001) used this principle to test whether synaesthetic colours are triggered pre attentively. They selected graphemes which elicit the colours red, green, blue and yellow for each synaesthete and presented one grapheme surrounded by four other (same) graphemes to form a cross shape (Hubbard & Ramachandran, 2005). This was presented to either the left or right of the screen for 100ms while looking at the central fixation cross, the task being to indicate what the central grapheme was. Results were mixed, with three of the synaesthetes performing better than controls, and no difference evidenced for the other three. Furthermore, control participants who completed trials in which the graphemes font was actually coloured performed significantly better than synaesthetes. This suggests that for some synaesthetes the colours may occur pre attentively, but that synaesthetic colours are not as strong as real colours.

This task has been replicated, except that a pattern mask was also presented for 250ms (Ward et al., 2007) and a larger sample of 14 synaesthetes (seven projectors, seven associators) was tested. Although there was a general trend for projectors to be better at the task than associators, this difference was not significant. In an elaboration of this design, the relationship between behaviour and phenomenology was explored more fully as all seven of the projectors and one associator reported having colour experiences. Graphemes were instead either surrounded by four nonsense symbols, or three symbols and one distracting grapheme, and synaesthetes indicated whether they saw the grapheme and colour, saw the grapheme only, saw colour only, or saw nothing. Six of the projectors and one associator reported colour, and for the symbol and grapheme distractor version, behaviour predicted phenomenology as trials in which the grapheme was correctly identified were more likely to be accompanied by a colour for the six projectors who saw colour. However, there were also trials in which no

grapheme was seen, but a colour was still experienced. These results support the projector/ associator divide, and provide interesting investigation of the relationship between phenomenology and behaviour. More detail of what colours were seen would allow us to determine whether the colours were actually pre attentive, or occurred after the grapheme was identified. Furthermore, both the Hubbard et al. (2005) and Ward et al. (2007) studies had accuracy levels well above chance, showing that detection levels were relatively high and a reasonable level of attentional awareness had remained.

#### **1.5.4. Shifts of attention**

Phenomenological reports suggest that GC synaesthetic concurrents are experienced only for graphemes in the attentional window (Ward et al., 2010). This coincides with how local and global shifts of attention can coincide with experienced colour. WO, when viewing Navon numbers such as a large 5 made up of smaller 2's, experienced the concurrent colour for the number (either local or global) attended to (Palmeri et al., 2002). Similarly, manipulating the size of an attentional window alters interference effects (Sagiv et al., 2006). The digits 2 and 7 were presented at the screen periphery (in white), and 200ms later dots which are coloured the concurrent for one of the digits (as seen by the two synaesthetes). These are either grouped near the centre of the screen, or around the peripheral digits so that the attentional window either includes the irrelevant digits or not. Participants indicated the dots colour. When the attentional window included the digits, larger interference effects were measured than when attention was away from the digits, although the effect did not disappear entirely which the authors suggested may signify residual grapheme and colour binding without attention.

In an attentional blink task, a stimulus was presented in a string of images (Rich & Mattingley, 2010). Participants had to first identify the orientation of a grating



presented at the start of the image stream, drawing their attention. A grapheme was presented in the stream, either congruent or incongruent with a colour patch presented at the end: this had to be identified after the grating orientation. If the grapheme was included at the point in the stimulus stream which incurred the strongest attentional blink effect, the Stroop interference effect disappeared compared to if the grapheme was presented out with the attentional blink timeframe. This supports the need for attention to trigger the concurrent colour.

By incorporating an additional task to manipulate attentional load, Mattingley, Payne and Rich (2006) measured manipulations from a synaesthetic Stroop task where participants named the colour of a target patch presented after a grapheme which was surrounded by a segmented diamond shape. On each side of the diamond was a gap, and after naming the target colour participants stated which side had the larger gap. In the low load task the size difference was large and therefore easy to determine, in the high load task the difference was minimal and harder to judge. When the colour target was incongruent to the grapheme concurrent for the synaesthetes, RTs were significantly longer than for congruent trials. Further, this effect was modulated by task load, with a smaller difference in RTs between congruent and incongruent RTs for the high load trials which demanded greater attention, than for the low load trials. Attention therefore appears to modulate behaviour in GC synaesthesia.

### **1.5.5 Synaesthesia and awareness of the inducer**

Another associated question is whether fully attending a grapheme, but without conscious awareness would be enough to trigger the concurrent colour and grapheme binding. There is an array of evidence to show that attention is required to induce the colour concurrent, however the experience of colour photisms without knowledge of

what grapheme had been presented (Ward et al., 2007) suggests synaesthesia without conscious awareness. How could this occur? Can a synaesthetic inducer bind with its concurrent without conscious awareness? In order to test this hypothesis, behavioural influences would have to be measured in response to stimuli processed without conscious perception. Furthermore, although a participant may believe that they did not perceive a stimulus (subjective criterion), they may still perform better than chance. To demonstrate the stimulus really wasn't perceived, they would need to perform at chance level during forced-choice detection (objective criterion) (Lin & He, 2009).

To test whether conscious perception of a grapheme was required to trigger the concurrent, Mattingley, Rich, Yelland and Bradshaw (2001) used masking, a technique where a stimulus is presented for a short duration, with an irrelevant meaningless image presented immediately after to suppress the conscious detection of the stimulus (Faivre et al., 2012). They masked a grapheme and presented a coloured target in a congruent, incongruent or neutral colour. When the grapheme was presented for 500ms (a long duration and therefore consciously seen), RTs for indicating the target's colour were significantly longer when the grapheme and colour patch were incongruent or neutral, then when the colour patch was the same as the concurrent for that synaesthete. However, when the graphemes were only presented for 56 or 28ms, the interference effects were eliminated. This was given as evidence that the grapheme does not bind with its concurrent pre consciously. To substantiate that it was not due to insufficient time for the colour to be generated, this task was repeated with a 500ms delay before the onset of the colour target, and the same lack of interference was measured. Furthermore, although grapheme identification at these durations was low, when a grapheme target rather than colour target was used, control participants demonstrated interference effects for incongruent (different prime and target graphemes) compared to congruent trials

(although the difference was only 21 and 7ms, respectively). Priming a grapheme may be possible at these short durations, but it doesn't inform whether a connected experience in another modality could be triggered with this level of processing.

Binocular rivalry (where two different images are presented, one to each eye), doesn't cause images to become merged, rather they tend to alternate from one back to the other and so forth (Lin & He, 2009), and more rarely merges or mosaics of images are created causing mixed dominance (Kim, Blake, & Palmeri, 2006). Both real colour and synaesthetic colour cause perceptual grouping in binocular rivalry, increasing their conscious perception in comparison to the rival image (Kim et al., 2006). Synaesthetic colours can therefore increase the conscious perception of a normally consciously transient image.

Bidirectionality of synaesthetic response has been demonstrated when deciding which in a pair of digits is larger, as when presented in colours suggesting a larger distance along the number line than they actually are (i.e. displaying the digits 4 and 5 in the colours for 2 and 7) RTs are shorter than if they are presented in the correct colours (Cohen Kadosh et al., 2005). Colour therefore influenced the perceived magnitude of the number difference.

Other techniques which can be used to investigate consciousness are gaze-contingent crowding and continuous flash suppression which can present stimuli for extended periods of time without being perceived (Kouider, Berthet, & Faivre, 2011; Tsuchiya & Koch, 2005). These were used in this thesis to investigate whether a subliminally viewed grapheme would bind with its concurrent colour for GC synaesthetes in Paper 4 and will be described later in this paper.

## 1.6 Synaesthesia and mental imagery

A link between synaesthesia and mental imagery has been suggested. Barnett and Newell (2008) compared synaesthetes (mainly GC synaesthetes) to non-synaesthetes using a questionnaire which assessed the strength of a participant's visual imagery ability, the Vividness of Visual Imagery Questionnaire (VVIQ; Marks & Marks, 1973). Synaesthetes reported significantly greater mental imagery abilities in comparison to non-synaesthetes (Barnett & Newell, 2008). The link between synaesthesia and mental imagery was strengthened in a study of abilities of spatial forms of synaesthesia where ordinal sequences such as days of the week, months or numbers have spatial locations. For example, each month would have a special location which is within the wider arrangement of months each with their own special spatial location. Price (2009) investigated the link between spatial forms of synaesthesia and mental imagery using two questionnaires which measure mental visual imagery, the Subjective Use of Imagery Scale (SUIS; Reisberg, Pearson, & Kosslyn, 2003) which measures spontaneous use of visual mental imagery, and the Object–Spatial Imagery Questionnaire (OSIQ; Blajenkova, Kozhevnikov, & Motes, 2006) which measures visual and spatial imagery ability. Price found that the spatial form synaesthetes reported significantly higher levels of visual imagery on the SUIS, and the visual subscale of the OSIQ than control participants. However for the spatial imagery OSIQ subscale there was no significant difference. The combined findings of Price (2009) and Barnett and Newell (2008) support the assertion that at least visual mental imagery ability is linked to synaesthesia.

To better understand the relationship between mental imagery and synaesthesia, Spiller, Jonas, Simner and Jansari (2015) compared synaesthetes with a range of different inducer and concurrent pairings against non-synaesthetes. Six questionnaires

were used, the VVIQ, SUIS, Clarity of Auditory Imagery Scale (CAIS; Willander & Baraldi, 2010), Vividness of Olfactory Imagery Questionnaire (Gilbert, Voss, & Kroll, 1997), Vividness of Movement Imagery Questionnaire (Roberts, Callow, Hardy, Markland, & Bringer, 2008) and an adapted version of the shortened Betts' Questionnaire Upon Mental Imagery (Sheehan, 1967). Spiller and colleagues (Spiller, Jonas, Simner, & Jansari, 2015) supported previous studies by showing that synaesthetes reported significantly higher mental imagery than controls. Furthermore, they showed that synaesthetes with a concurrent or inducer in a specific modality (such as taste) reported significantly greater mental imagery in that modality than synaesthetes who didn't have a linked concurrent or inducer. Therefore synaesthetes don't only report greater levels of mental imagery overall, but this is also linked to their particular type of synaesthesia. This demonstrates the strong link between synaesthesia and mental imagery, however behaviour on tasks related to these modalities was not measured and should be assessed in future research.

## **1.7 Overview of Papers**

### **1.7.1 Overview Paper 1**

There was only one published study, when this thesis was started, where synaesthesia-like experiences were induced in high susceptible participants (Cohen Kadosh, Henik, Catena, et al., 2009). This study measured an impairment in performance which is easier to produce through demand characteristics (Spanos, 1986) than an advantage.

Furthermore the reports of phenomenological experiences were somewhat vague for stringent comparison to developmental synaesthete's phenomenology. A task which had been used extensively is the embedded-figure visual search task which GC synaesthetes often complete with increased accuracy compared to non synaesthetes (Hubbard et al., 2005; Hubbard & Ramachandran, 2005; Ward et al., 2010). Quantitative values for

phenomenology are also known for this task (Ward et al., 2010) so both behaviour and experience could be compared for the hypnotic synaesthetes against known measures.

High susceptible participants completed an embedded-figures task with digitised 2's making a shape (square, rectangle, triangle, diamond) surrounded by mirror image digitised 5's. Trials lasted 1, 2, 3 or 4 s, and the experiment was completed twice, once at baseline and once with a hypnotic suggestion to see the digit 2 as vividly green, and 5 as vividly red. In each trial, the embedded shape was chosen using a 4AFC decision, then the percentage of digits appearing as coloured and the vividness of any colours experienced (1= no colour, 6 = very vivid colour) was indicated.

Accuracy didn't improve in the hypnosis condition even though many of the participants did experience colour for the digits. The percentage of digits in the array coloured, and the vividness of their colours was actually comparable to that of developmental synaesthetes on the same task (Ward et al., 2010). Interestingly, after a median split so that those who experienced lots of colour could be compared to those who experienced little colour, differences between accurate and inaccurate trials were evident. Those who experienced lots of colour reported a higher percentage of digits within the array as coloured, and more vivid colours, for accurate compared to inaccurate trials. Interestingly, this finding suggested that the colour was added after the shape had been detected within the array rather than helping in the identification of the embedded shape. Even after a median split, accuracy was not higher for the hypnosis compared to baseline condition. Overall, it appeared that high susceptible participants could be given hypnotic suggestion to feel like a synaesthete, but not behave like one.

### 1.7.2 Overview Paper 2

In Paper 1 it was shown that hypnotic suggestion to experience a GC synaesthesia type hallucination didn't produce a behavioural advantage, and that mental imagery may have been part of the production of the colours. This was because more colour was experienced for accurate compared to inaccurate trials, and once the shape had been detected within the array, it would be easier to add the colour. In the second hypnotic synaesthesia experiment, mental imagery ability was therefore recorded so this could be correlated with behaviour. A different type of synaesthesia was chosen for the suggestion, motion-sound (MS) synaesthesia. This was because very little is known about MS synaesthesia, with only one published experiment at the time (Saenz & Koch, 2008). Also, it was known that auditory hallucinations can be generated (Bowers, 1998) as well as sound through auditory mental imagery (Willander & Baraldi, 2010). This study used the same paradigm as the only study of MS synaesthesia (Saenz & Koch, 2008). Pairs of either auditory or visual sequences similar to Morse code had to be differentiated as same or different. The auditory sequences were beeps, visual ones were flashing white circles. As there is an advantage for auditory compared to visual trials in general, Saenz and Koch found that the MS synaesthetes performed better than controls for visual trials only as they had the auditory concurrent to aid them.

In Paper 2, MS synaesthetes completed the sequence differentiation task once as they naturally have an auditory concurrent. Low, medium and high hypnotisable non-MS synaesthetes completed the experiment twice: once at baseline and once with suggestion to hear beeps for the flashing circles. All non-MS synaesthetes received the same suggestion, but high participants received an induction first. It therefore acted as a post-hypnotic suggestion for the high susceptibility participants, and a mental imagery

instruction for low and medium susceptibility participants. The suggestion was triggered by a clap of the hands.

It was found that the MS synaesthetes were significantly more accurate than the low susceptible group at baseline for visual trials, therefore the MS synaesthetes did have a general advantage for the task presumably due to their auditory concurrents. However, neither the post-hypnotic or mental imagery suggestion improved performance in the experimental block for the non-MS synaesthetes. Many of the non-MS synaesthetes used beeps spontaneously as a strategy for the visual trials at baseline, however they were not more accurate than participants who didn't use this strategy. Further, general visual or auditory imagery ability did not correlate with accuracy. It was therefore shown that MS synaesthesia is not due to mental imagery, and that deliberately using mental imagery doesn't improve accuracy.

Overall, Paper 1 and Paper 2 showed that hypnosis can produce the phenomenology of synaesthesia, but not associated behaviour advantages. This suggests synaesthetic behaviour is due to more than phenomenological influences like those created with hypnosis. Synaesthetes must have either learnt how to use the concurrent over time, or more likely, special neuroanatomy is also required for synaesthesia. The similarity in reported phenomenology between the hypnotic and developmental synaesthetes is remarkable, and by distinguishing the differences between them what causes synaesthesia could be uncovered.

### **1.7.3 Overview Paper 3**

As the two main measures of synaesthesia projector and associator phenomenology had never been formally assessed, responses were collected from GC synaesthetes on the RSPA (Rouw & Scholte, 2007) and ISEQ (Skelton et al., 2009) and tested using Factor



Analysis. This allows correlations within the data to group the questions so that subcomponents to a construct can be identified, and the reliability of these subcomponents assessed. To classify a synaesthete in the RSPA and ISEQ, the mean associator value is subtracted from the mean projector value. This assumes that phenomenology of GC synaesthesia is a continuum, with associator at one end of the bimodal distribution, and projector at the other. Although Skelton et al. noted that some synaesthetes do not neatly fall into one sub type or another, in their questionnaire they are called ‘undetermined’, without conducting factor analysis it can’t be known for sure that phenomenology is indeed one dimension. Responses from the Coloured Letters and Numbers (CLaN) questionnaire (Rothen, Tsakanikos, Meier, & Ward, 2013) were also gathered as this is the only synaesthesia questionnaire tested using factor analysis.

Exploratory factor analysis was conducted on each questionnaire individually. The process involved removing questions which did not correlate well with the other questions, and repeating the analysis until the questions were grouped with a valid and reliable factor structure. Both questionnaires were reduced during this process, however both retained the same question divide between projector and associator questions, although these were not in one factor. Both questionnaires contained two factors which corresponded to the projector/ associator divide. Therefore, the phenomenology is not one continuous dimension, rather two independent measures which can overlap, as some synaesthetes scored highly on both projector and associator questions. Correlational analysis against the dimensions of the CLaN validated the revised questionnaires.

As GC synaesthete sub groups are compared in many synaesthesia experiments, it is important to define them correctly. From Paper 3 it became clear that treating GC synaesthesia phenomenology as one continuous dimension is not appropriate, and that

projector and associator dimensions should be treated independently for the calculation of group. Differences between projector and associator synaesthetes in terms of measured behaviour is inconsistent, and this may be due in part to not identifying the subgroup of participants accurately. Using the revised questionnaires produced through factor analysis may reduce the noise in these studies.

#### **1.7.4 Overview of Paper 4**

In Paper 4 the link between consciousness and synaesthesia was researched using two techniques not employed previously in GC synaesthesia research. Previously it has been shown that masked graphemes can prime another grapheme (Mattingley et al., 2001), however this doesn't mean that they necessarily prime a colour strongly enough to influence colour detection (Blake, Palmeri, Marois, & Kim, 2005) or that the grapheme was processed enough to trigger the colour. Mattingley has also stated that the unconscious priming effect may not be evident in all synaesthetes and that group analysis may not be an appropriate method of investigation (Mattingley, 2009). Rather than look at small samples or individual cases, which is often the case with synaesthesia research, I chose to look at large samples using techniques which would provide longer exposure to a priming stimulus without conscious awareness, to strengthen any priming effects. This would prevent unrepresentative individual differences (Rothen & Meier, 2009) from clouding understanding of consciousness and synaesthesia.

Using peripheral crowding, the conscious awareness of a stimulus can be reduced. As the peripheral presentation relies on participants viewing the fixation point rather than diverting their view to the crowded stimulus, a short stimulus duration can reduce the chances of it being viewed foveally (Hubbard & Ramachandran, 2005). This limits the length of time that a stimulus can be presented. *Gaze-contingent crowding*

(GCC, also called *gaze-contingent substitution*) uses eye tracking to more tightly control what the person views. Like in peripheral crowding, the priming image is surrounded by distractors. By tracking the direction of gaze, and predefining the acceptable window of attention around the fixation deemed acceptable for eye fixation without being too close to the crowded image, prime viewing can be controlled. Another almost identical image, with no prime included, is presented when gaze deviates from fixation out with the predefined window. The prime is therefore viewed peripherally when fixation is within the window, and the crowding only is viewed when away from fixation. This prevents the prime ever being viewed foveally. Both static and dynamic images can be shown for several seconds without being consciously seen (Kouider et al., 2011). This provides highly controlled viewing for long durations.

In binocular rivalry, which was discussed earlier, two different images are presented, one to each eye. The consciously perceived image tends to alternate between the two. *Continuous flash suppression* (CFS) is similar in that a different image is presented to either eye, but the consequences are different. The dominant eye views a constantly changing, high contrast image, such as an alternating Mondrian image (many overlapping squares of different colours or shades of grey). A static image is presented to the other eye. Initially, only the high contrast alternating image is consciously perceived (for as long as three minutes) before the static image suddenly ‘breaks through’ into conscious awareness (Lin & He, 2009). By measuring conscious awareness we are able to investigate unconscious processing (Kouider et al., 2011; Stein, Hebart, & Sterzer, 2011). Differences in static image can influence the time it takes for it to be consciously perceived, showing that the image is being processed pre consciously. This technique can therefore be used to study pre conscious processing and percept binding.

In Paper 4, whether a grapheme binds with a concurrent colour for GC synaesthetes was investigated using these two techniques. In Experiment 1, GCC was used to present a digit (1, 2, 3, 4, 6, 7, 8 or 9) for 2.5 s without the participant being consciously aware of it. After the priming period, several different tasks were completed. In Experiment 1A, participants had to decide whether the central target number presented after the crowded digit was greater or less than 5. The number could either be congruent (was the same as the primed number, or required the same button response) or incongruent (was a different number, or required a different button response). This task was designed to show that the number was being primed. Although priming effects were not reflected in the RTs, more errors were made for incongruent compared to congruent trials, showing that the digits had been primed. In Experiment 1B, rather than showing a central target digit, a central colour patch was presented which matched one of four digits presented in that experiment and was individually tailored for each GC synaesthete. In each trial, the peripherally presented digit and target colour could either be congruent or incongruent. Synaesthetes had to indicate the target colour through a 4FC button press, and their response could therefore be correct or incorrect. There was no difference in either the RTs or error rates for congruency of digit and target colour. This suggests the grapheme did not bind with its concurrent colour to influence behaviour. In Experiment 1C synaesthetes and controls completed a prime identification task, choosing which digit was being presented peripherally. Confidence was rated, and colour experienced/ vividness of colour for synaesthetes. Colours increased the confidence synaesthetes had in their answer, but not their accuracy. Interestingly, colours were more likely to match the digit the synaesthete chose than the digit they viewed.

In Experiment 2, CFS was used to test whether a pre consciously presented grapheme would bind with its colour and influence the time it took for the grapheme to break through into awareness. In Experiment 2A, graphemes were chosen for each synaesthete, which either had a colourful concurrent (like red, green) or a greyscale concurrent (like black, grey). As colour aids in conscious perception it was hypothesised that if the grapheme bound with the concurrent, then graphemes with a colourful concurrent should break through faster than those with a greyscale concurrent. A grapheme was presented in black and the participant stated the grapheme name into the microphone as soon as they saw it. There was no difference in RTs between graphemes which had a colourful or greyscale concurrent. In Experiment 2B, graphemes that evoked red, green, blue or yellow were chosen and presented in either the congruent or incongruent colour. If they bound preconsciously, then congruent graphemes would be expected to break through faster, but this was not found. In Experiment 2C, a more standard Stroop task was run using CFS except that they stated the word not colour (control participants only). Incongruently coloured colour words broke through slower than congruent or neutral words. There were also more errors for incongruent than congruent or neutral words. Therefore, colour words bound with their colour preconsciously, but for GC synaesthetes the grapheme didn't bind with the colour. Measures in Experiments 1 and 2 were also correlated with the CLaN and R-RSPA questionnaires.

The question of whether a synaesthetic inducer binds with its concurrent when viewed unconsciously appears answered. Investigating this question using several difference techniques is of great importance. Mattingley et al. (2001) used masking to prevent conscious perception of the grapheme, and in this thesis GCC and CFS were

used. As unconscious GC synaesthesia concurrents are not primed using any of these techniques, the grapheme and colour do not bind preconsciously.

### **1.8 Discussion**

This thesis set out to learn more about the conscious experience of synaesthesia. Using hypnosis, it has been shown in Paper 1 and Paper 2 that hypnosis can produce the phenomenology of GC and MS synaesthesia, but not the behaviour. The lack of behaviour improvement typical of developmental synaesthetes on the embedded-figure, or sequence differentiation task showed that feeling like a synaesthete was not enough to behave like one.

It has become clear that both attention and conscious detection of an externally presented grapheme is required for the synaesthetic GC concurrent to be triggered and bound to the grapheme. A lack of colour priming using GCS, or difference in break through time using CFS in Paper 4 demonstrated this. This supports a wealth of research into the requirements of attention and consciousness in GC synaesthesia research. Paper 4 was however the first to allow a realistic duration for the concurrent colour to bind with the grapheme and provided conclusive evidence for the attention and consciousness needed in GC synaesthesia.

It was very interesting that in Paper 4, many GC synaesthetes reported colour experiences in the grapheme detection task, even when the grapheme was incorrectly identified. Colours were even reported which did not match any of the 4AFC grapheme options. This was reported by several of the synaesthetes themselves during testing, as they were somewhat confused. As it was more likely for the colour to match the chosen digit than the presented one, this shows that a synaesthetic concurrent can be created from an internally generated inducer.

It became clear as research for this thesis progressed, that phenomenology is an important and central aspect of synaesthesia research which is at times overlooked. In Paper 1, hypnotic suggestion created phenomenology remarkably similar to that of developmental GC synaesthetes. In Paper 2, many of the non-MS synaesthetes spontaneously used beeps similar to those heard by MS synaesthetes to aid in the sequence differentiation for visual trials. Synaesthetic phenomenology can therefore be experienced by non synaesthetes. In Paper 3 the classification of GC synaesthetes as projector or associator was found to be at times unrepresentative, as these are distinct dimensions which can both be experienced by some synaesthetes rather than one or the other. Then in Paper 4, colours experiences were linked more to choices made by GC synaesthetes than digits viewed. It is therefore clear that phenomenology of synaesthetes should be considered in more detail than a general consistency score.

Mental imagery was another common theme within this thesis. In Paper 1, mental imagery was thought to explain the differences in phenomenology measures between accurate and inaccurate trials, as after a shape is identified it is easier to project colour on post-hoc. In Paper 2 mental imagery was included but didn't account for the variation in task ability. Mental imagery could also possibly account for the colours experienced by GC synaesthetes in Paper 4 that matched the digit they chose rather than the digit they saw. Early visual detection processes can't account for the colour generation in these trials. Rather, after choosing the digit a colour is then being triggered, and this is from an internally generated percept. These colours may therefore either be mentally generated, or more general colour associations.

There is a debate in both the hypnosis and synaesthesia literature on whether they are due to neuroanatomical differences or functional differences. In this thesis hypnosis, a largely debated topic with high variability and a low presence of high

susceptible individuals, was used to research synaesthesia. Synaesthesia itself however is another debated area with high variability and a low prevalence. The general consensus of both research areas is that the opposing theories need to be integrated to include both neuroanatomical and functional mechanisms.

Phenomenology without behaviour was found in Paper 1 and Paper 2 when researching hypnotic synaesthesia. Phenomenology without conscious awareness was evident in Paper 4 when researching GC synaesthesia. Combined these demonstrate the importance of the mechanisms underlying behaviour *and* phenomenology and the need to consider both when researching hypnosis or synaesthesia.

The phenomenology of MS synaesthesia needs to be explored more thoroughly, as only brief descriptions have been given so far (Saenz & Koch, 2008). If MS phenomenology is based primarily on sounds naturally associated with movement, in what way is it different from learnt associations? Hearing movement seems like a far more natural connection than, for example, seeing colour for letters, so why is it so rare in comparison? To what extent are MS concurrents idiosyncratic, and are they consistent? As this thesis has shown phenomenology can be quite variable across synaesthetes and impact on behaviour, knowing more about the MS synaesthetic experience would benefit experiment design. Development of an MS synaesthesia questionnaire could help locate more synaesthetes to take part in research since so few of them have thus far been discovered.

Apparent motion, where two displays with tokens in different places are shown in quick succession and therefore perceived as moving, can be influenced by GC synaesthetic colours grouping tokens and therefore the direction of motion (Kim et al., 2006). By manipulating the difference between the tokens, MS synaesthetes may have a



lower threshold for detecting apparent motion. It may also be possible to manipulate this effect if sounds similar to their concurrent for motion is played to them through headphones, compared to completing the same task in silence. This way, a more motion based task could be used rather than flashing lights which although producing sound are only one way in which the sound of MS synaesthetes is triggered.

The difference between a mentally imagined colour and a synaesthetic colour need to be researched more fully in GC synaesthesia. Thus far studies have investigated overall differences in ability, but this doesn't inform us of the differences between these at a phenomenological level for the individual, or from a neurological perspective. If a colour can be triggered from a mentally generated grapheme, how does this differ from one triggered by external low level feature detection and grapheme identification? Although several studies have looked at behavioural differences between projector and associator synaesthetes (Dixon et al., 2004; Rouw & Scholte, 2007; Ward et al., 2010), how this interplays with mental imagery could be researched further. Associator synaesthetes may be better at mentally viewing their colours or manipulating them in their minds eye, whereas projectors may rely more heavily on the external visual stimulus. Conversely, 'know' associators may be poorer at mental imagery, and projectors superior (Simner, 2013).

As hypnotic synaesthesia appears to have the same phenomenology as developmental synaesthesia but different behaviour, it would be useful to see at what point these two experiences diverge. Using EEG it would be possible to research any difference in pattern between a developmental GC synaesthete and a hypnotic synaesthete viewing a grapheme which evokes a colour. As differences have been measured already in GC synaesthetes (Barnett, Foxe, et al., 2008) and hypnosis has been used to reduce interference effects in a face-colour synaesthete (Terhune, Cardeña,

& Lindgren, 2010) the differences between transient and developmental synaesthesia could be investigated.

Overall, this thesis has confirmed the importance of researching synaesthesia from both a phenomenological and behavioural perspective simultaneously. It has been shown that synaesthesia requires conscious awareness for it to influence behaviour, even though phenomenology may be experienced without consciously detecting a grapheme for GC synaesthetes. The experience of phenomenology in hypnotic synaesthesia without behaviour also confirms that the behaviour of synaesthetes is due to more than the functional linking of inducer and concurrent.

## CHAPTER 2:

### CAN GRAPHEME-COLOUR SYANESTHESIA BE INDUCED BY HYPNOSIS?

#### -PAPER 1

##### 2.1 Abstract

Grapheme-colour synaesthesia is a perceptual experience where graphemes, letters or words evoke specific colours, which are experienced either as spatially coincident with the grapheme inducer (projector sub-type) or elsewhere, perhaps without a definite spatial location (associator sub-type). Here, we address the question of whether synaesthesia can be rapidly produced using a hypnotic colour suggestion to examine the possibility of ‘hypnotic synaesthesia’, i.e. subjectively experienced colour hallucinations similar to those experienced by projector synaesthetes. We assess the efficacy of this intervention using an “embedded figures” test, in which participants are required to detect a shape (e.g., a square) composed of local graphemic elements. For grapheme-colour synaesthetes, better performance on the task has been linked to a higher proportion of graphemes perceived as coloured. We found no performance benefits on this test when using a hypnotic suggestion, as compared to a no-suggestion control condition. The same result was found when participants were separated according to the degree to which they were susceptible to the suggestion (number of coloured trials perceived). However, we found a relationship between accuracy and subjective reports of colour in those participants who reported a large proportion of coloured trials: trials in which the embedded figure was accurately recognised (relative to trials in which it was not) were associated with reports of more intense colours occupying a greater spatial extent. Collectively, this implies that hypnotic colour was only perceived after shape detection rather than aiding in shape detection via colour-based perceptual grouping. The results

suggest that hypnotically induced colours are not directly comparable to synaesthetic ones.

## 2.2. Introduction

Individuals with grapheme-colour synaesthesia experience a colour (concurrent) when viewing particular letters, numbers or grammatical symbol (inducer). The triggered colour experience is automatic (Mattingley et al., 2001) and the concurrent colour is consistent over time (Simner et al., 2005). The developmental form of synaesthesia emerges early in life (Simner, Harrold, Creed, Monro, & Foulkes, 2009), is associated with genetic differences (Tomson et al., 2011), and also structural and functional differences within the brain (Hubbard et al., 2005; Rich et al., 2006; Rouw & Scholte, 2007; Weiss & Fink, 2009). Early development may not be the only pathway for the emergence of synaesthetic experiences (unless, of course, one chooses *a priori* to limit the term ‘synaesthesia’ to particular causal mechanisms). It has long been known that synaesthesia can be acquired as a result of sensory loss (Armel & Ramachandran, 1999) or temporarily after taking hallucinogenic drugs (Luke & Terhune, 2013; Sinke et al., 2012). More recently, synaesthesia has been reported to arise after brain damage (Ro et al., 2007) and it has also been suggested that synaesthesia may arise, in blind individuals, after expertise with sensory substitution technology (Ward & Wright, 2012; see also Farina, 2013; Ward & Meijer, 2010). Finally, it has been claimed that synaesthesia can be induced by hypnosis in hypnotically susceptible individuals (Cohen Kadosh, Henik, Catena, et al., 2009). In the present study we re-examine this claim using an ‘embedded figures’ test that has been widely used in grapheme-colour synaesthetes. The benefit of this task is that evidence for synaesthesia type behaviour would be measured through task improvement, rather than through deficits, which are easier to produce through task compliance. The issue is of theoretical importance because positive findings would suggest that synaesthesia can (at least in some circumstances) arise from purely functional – rather than structural – brain changes (Grossenbacher & Lovelace, 2001) and, moreover, that hypnosis can create novel perceptual abilities.

Hypnosis is able to alter the phenomenological properties of participants' subjective experience (Kihlstrom, 2013; Oakley & Halligan, 2013). The process of hypnosis can be divided into induction and suggestion stages. In the induction stage, a putative 'hypnotic state' is induced, or expectations for experiences are heightened, or the subject is simply alerted that the context is appropriate for a certain sort of response (e.g. Kirsch, 2011; Oakley & Halligan, 2009); in the second stage, suggestions are given to the participant to experience a (potentially) wide range of physical and perceptual experiences. There is considerable variability both in individual hypnotic susceptibility (Bowers, 1998) and in the range of experiences that can be induced. Importantly, perceptual hallucinations (e.g. hearing music) can be induced in many participants (Bowers, 1998), providing a potential link to synaesthesia.

Although there is general consensus that hypnosis can alter a participant's subjective experience and this can then cause behavioural changes (Kihlstrom, 2013) the neural processes underlying the functional changes corresponding to hypnotically induced perception remain poorly understood. One class of theories postulates that highly hypnotisable people can perform tasks hypnotically they could not do otherwise; for example, distort perception so that they actually can see non-existent objects in a way they could not imagine (e.g., Brown & Oakley, 2004) or fail to perceive stimulation that would otherwise impinge on their awareness (e.g. as pain, Hilgard, 1986). Another class of theories postulates that highly hypnotisable people cannot do anything hypnotically that they could not do anyway (e.g. Sarbin & Coe, 1972; Spanos, 1986). One way of characterising the latter class of theory is in terms of "cold control" (Dienes, 2012), which postulates that the defining feature of acting hypnotically is simply the incorrect meta-cognition that one is not intending the (motor or cognitive) action. For example, hypnotic hallucination of an object on this account is imagining the object, but without realising

that one is deliberately creating a visual representation: It appears to occur from other causes and thus appears as perception (Dienes & Perner, 2007). That is, according to cold control, hypnotic responding involves no new abilities, just the sense that an action is happening by itself. The two classes of theory can be tested by using suggestions for abilities not already possessed by subjects: If the subject gains abilities they did not have, the second class of theory is refuted. As we will argue, suggestions for synesthetic experiences can serve this function. Synesthetic experience has some perception-like qualities that may enable performance on some tasks (Ramachandran & Hubbard, 2001) so the question arises whether hypnotically-induced synesthetic experience is more perception-like than imagined synesthetic experience.

The generation of synesthetic experience appears automatic, and automatic processes are partially defined by the difficulty in controlling them. So the question is raised whether control of synesthetic experience might be greater hypnotically rather than non-hypnotically. One developmental form of grapheme-colour synaesthesia has been temporarily reduced through hypnotic suggestion. Terhune, Cardeña, and Lindgren (2010) abolished the phenomenological synaesthetic experiences in AR, a synaesthete who experiences colours when viewing faces. She had to name the colours of face stimuli which were presented in either congruent or incongruent colours. Stroop-like interference effects were evident in comparison to controls in both reaction times (RTs) and event related potentials (ERPs) at baseline, however, after a post hypnotic suggestion these were no longer evident. This indicates the relevance of synaesthesia to testing theories of hypnosis, as well as for hypnosis for testing theories of synaesthesia. We will consider the converse case to that of Terhune et al., namely, of hypnotically suggesting a type of synaesthesia in people who did not previously experience it.

To create a 'hypnotic synaesthesia' one can use the suggestion that when seeing (for example) the letter A the participant will see a special red colour on the page. Supporting this idea, the phenomenological perception of colour (or no colour) has been manipulated using suggestion to add or drain colour from patterned stimuli (Kosslyn, Thompson, Costantini-Ferrando, & Spiegel, 2000). High but not low susceptible participants all reported being able to see grey-scale stimuli as coloured, and coloured stimuli as grey-scale when given hypnotic suggestion to do so. Further, positron emission tomography (PET) indicated changes in cerebral blood flow for left and right fusiform areas (perhaps corresponding to human V4) when hypnotic induction was used; however, non-hypnotically imagining the colour changes produced significant changes only in right fusiform cortex. Hypnosis appeared to influence activity in colour-sensitive areas of the brain in a way imagination alone could not.

The Kosslyn et al. (2000) study highlights the issue of demand characteristics in hypnosis research, and the tendency of subjects to either "hold back" or try harder in different conditions to produce the pattern of results they perceive as desired (Orne, 1962; Spanos, 1986). Specifically, the suggestion was more strongly worded in the hypnosis rather than the imagination condition in order that subjects would not confuse the two conditions and "slip into trance" in the imagination condition. Kirsch, et al. (2008) presented the identical colour adding or draining suggestions with or without hypnotic induction, and obtained substantial and near equivalent changes in colour perception in both conditions. (Further, subjects rated themselves as clearly not hypnotised in the non-hypnotic condition, indicating that slipping into trance was not a problem.) Thus, when demand characteristics were more nearly equalised the difference between hypnosis and non-hypnosis in subjective experience greatly diminished. Further, McGeown, et al. (2012) showed that similar activation in visual areas was produced in both the hypnotic



and non-hypnotic conditions. That is, as cold control theory predicts, hypnotic hallucination with the suggestions used by Kosslyn et al. (2000) may involve the same visual abilities as imagination, with the difference being purely metacognitive (Dienes, 2012).

There has been one previous attempt to hypnotically induce grapheme-colour synaesthesia (Cohen Kadosh, Henik, Catena, et al., 2009). Cohen Kadosh and colleagues assigned colours to digits either through post-hypnotic suggestion or learnt association (e.g. 5 = green). Participants were required to search for an achromatic (black) grapheme against a coloured background. The results showed that search was impaired when the suggested colour was congruent with the background. However, this result reflects a deterioration in performance which is easier to simulate (explicitly or implicitly) than an improvement. Cohen Kadosh et al. requested control groups to associate the colours with the digits in non-hypnotic contexts; the non-hypnotic request had no effect on the search task. However, a non-hypnotic request carries different demand characteristics from a hypnotic or post-hypnotic suggestion. It is also unclear from this study whether the performance on the task does indeed resemble that found in developmental grapheme-colour synaesthesia. To our knowledge only one developmental grapheme-colour synaesthete has been tested on a version of this task (Smilek et al., 2001). While performance of this synaesthete showed the same trend as the ‘hypnotic synaesthetes’ (i.e. worse performance on congruent trials, about 20%, compared to incongruent trials, about 90%), they were far from equivalent in other respects. Perhaps surprisingly, the manipulation had only a mild effect on the synaesthete (88 % correct for congruent and 96 % for incongruent conditions) but a drastic effect on the hypnotised non-synaesthetes. Although direct comparison of proportion correct trials is difficult due to differences in the task, the comparison is striking as the synaesthete completed a more difficult task than

the non-synaesthetes, being required to provide a specific grid location for the target grapheme amongst distractors. Furthermore, although behavioural similarities between developmental and hypnotic synaesthetes are informative of cognitive processes, they don't provide detail of the phenomenological experience of the participant, an aspect which requires more attention in hypnotic synaesthesia research as well as more generally in neuroscience (Lifshitz, Cusumano, & Raz, 2013).

In the present study, we re-examine whether hypnotically induced synaesthetic colours can lead to facilitated performance on the Embedded Figures Test. Although the test itself (and the interpretation of the results) is not without controversy, it has the advantage of predicting that synaesthetic (or hypnotically hallucinated) colours should facilitate rather than impair performance on a difficult task, as in the previous study. Moreover, the test has been utilised in several previous studies involving grapheme-colour synaesthetes providing useful benchmark comparisons. Ramachandran and Hubbard (2001) showed synaesthetes arrays comprising of different graphemes (e.g. 5s and 2s) such that one of the graphemes could be grouped together to form a shape (e.g. a triangle made of 2s)<sup>1</sup> (Ramachandran & Hubbard, 2001). The task was to identify the global shape, from four alternatives, given a limited viewing time of 1 second. Ramachandran and colleagues (2001) found their two synaesthetes to be significantly more accurate in identifying the embedded shape than controls. They later called this effect “pop-out” (Hubbard, Manohar, & Ramachandran, 2006).

The effect was partially replicated by Hubbard et al. (2005) who noted that the “pop out” effect was not as great as would be expected for true colour. Rothen and Meier

---

<sup>1</sup> In their original study there were always three kinds of graphemes presented, but the test is commonly illustrated by the example of 5s and 2s.

(2009) however did not find an accuracy advantage for synaesthetes in comparison to controls for the same task. Ward, Jonas, Dienes and Seth (2010) partially supported the original findings with their larger scale replication study involving a sample of 36 synaesthetes. Synaesthetes' accuracy at detecting embedded shapes was significantly higher than controls, though detection rates (41% for synaesthetes) remained significantly below that corresponding to true "pop out". In this study, participants were also required to rate the phenomenal vividness of the synaesthetic colour and to indicate what percentage of the digits appeared as coloured. Importantly, the greatest performance benefits were found for those synaesthetes who experienced a large proportion of the array as coloured. This was interpreted by proposing that synaesthetic colours may facilitate local grouping within a spatial window of attention but that synaesthetic colours do not enable pre-attentive pop-out. The latter interpretation may explain why other studies, based on more standard visual search paradigms, have often failed to find any benefit of synaesthetic colours in detecting a target achromatic singleton grapheme (Edquist et al., 2006; Sagiv et al., 2006). Once a grapheme has been attended to it evokes a colour and improves visual search (Wolfe, 1994) as it allows the synaesthete to discard distractor graphemes faster or reduce their likelihood of returning to the discarded grapheme again through local perceptual grouping (Sagiv & Robertson, 2005). That is, synaesthesia may assist local grouping of elements on the basis of colour (facilitating the embedded-figures test) but synaesthetic colour may not enable pre-attentive pop-out (on more standard visual search).

As noted by Ward et al. (2010), grapheme-colour synaesthetes differ in the extent to which they perceive (or notice) their synaesthetic colours during this task. Synaesthetes classed as 'projectors', i.e. who report their colours in the spatial location of the grapheme, were more likely to report colours (and showed a trend to do better overall on

the task). The reasons for this are not completely understood (Ward et al., 2010; Ward, Li, Salih, & Sagiv, 2007). Nevertheless, for the present purposes we decided to optimise the chances of obtaining a significant result by instructing our highly hypnotisable participants to project colours onto the array of graphemes. If hypnotic suggestions can create grapheme-colour synaesthesia then hypnotically hallucinated colours will facilitate performance on this task (relative to a no-suggestion control condition). We also ask, if hypnotic grapheme-colour synaesthesia can be induced, are the perceptual reports similar to those of natural synaesthetes in regards to the vividness and percentage of coloured digits?

### **2.3 Method**

A counterbalanced two (condition; hypnotic suggestion versus no-suggestion) by four (duration; 1, 2, 3 and 4 seconds) within subjects design was used.

#### **Participants**

Fourteen participants aged 18 - 42 ( $M = 23.2$ ,  $SD = 6.3$ ) were recruited through the University of Sussex Hypnotic Susceptibility Register. Each had previously been screened using the Waterloo-Stanford Group Scale of Susceptibility, form C (Bowers, 1998) with a score of 8 or higher being used to classify them as highly susceptible. This corresponds to the upper 10% of people screened. Scores ranged from 8 – 11 ( $M = 9$ ,  $SD = 1.04$ ). Each was paid £5 for participation, the whole experiment lasting approximately one hour. No participant reported having any type of synaesthesia, this was asked prior to testing. The study was granted clearance from the University of Sussex ethics committee.

## **Materials**

The embedded figures stimuli consisted of four shapes (squares, rectangles, triangles and diamonds) of number 2s embedded in an array of 5s taken from the Ward et al. (2010) study. Each shape was made from 6 to 10 target 2s surrounded by 41 distractor 5s, all of which were in black font. Participants sat approximately 85 cm from a 15" LCD monitor with 60 Hz refresh rate. The shape location differed across trials, not always appearing in the centre. E-prime 2.0 software was used to run the experiment.

## **Procedure**

The experiment was repeated twice within each session, counterbalanced so that half of the subjects completed the hypnosis condition first, and the other half the control. Participants were not informed that the study would include hypnosis until just prior to the hypnosis condition to avoid 'hold back' (Stam & Spanos, 1980) where participants may unconsciously perform poorer in the baseline condition than they were capable of.

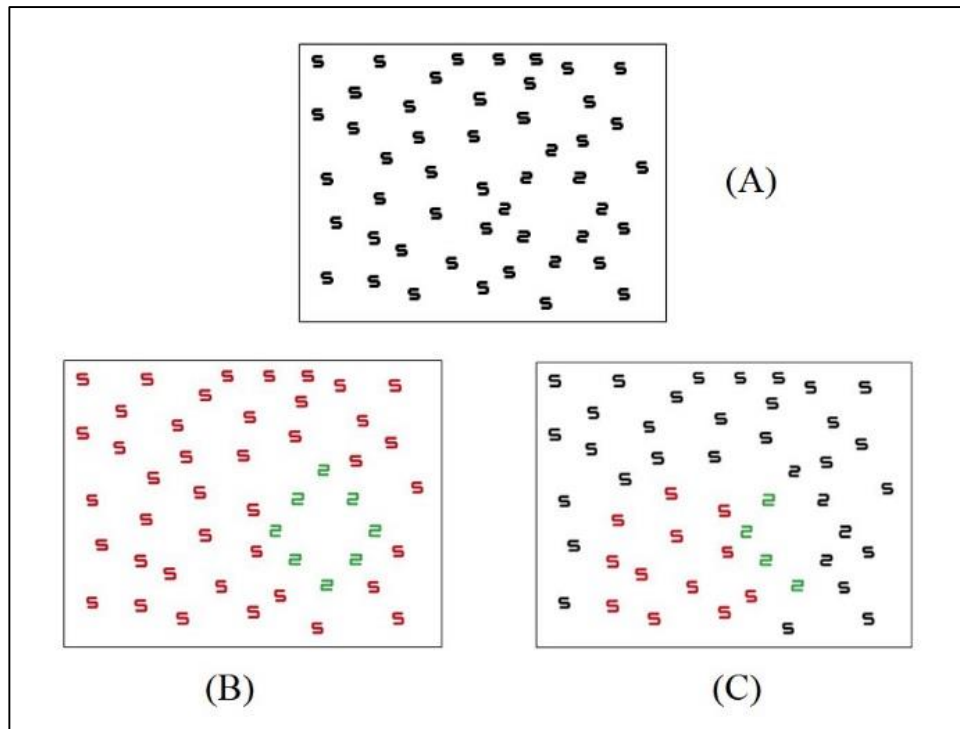
The experiment consisted of four blocks which were completed twice, once to obtain a measure of general baseline ability and once with a hypnotic suggestion to experience colours for the numbers in the display. For half of the participants the block order was ascending (1 to 4 seconds stimulus duration), for the other it was descending (4 to 1 second). In the hypnosis condition, participants received a brief induction (where the participant was asked to become relaxed and counted down into a deep hypnotic state) before a hypnotic suggestion to see green for 2 and red for 5 on the monitor where the digit was, very much like a projector synaesthete. Prior to each of the four hypnosis blocks, the suggestion was reinforced by getting the participant to focus on an individual stimulus digits and attempt to enhance the colour. This was done for both the 2 and 5. If they did not see any colour, they were asked to attempt to visualise it as coloured as best

they could. Figure 2.1 shows how the stimulus would be coloured if colour experiences phenomenologically similar to those of natural synaesthetes were evoked using hypnotic suggestion. When completing the four control blocks, no specific instructions were given on how to complete the task. Whether the participant started with the hypnosis or control condition was counterbalanced.

### **Suggestion for hypnotic grapheme-colour synaesthesia**

The following suggestion was used to induce GC synaesthesia-like experiences in the participants during the hypnosis blocks.

“Now you will see on the computer screen many 2s and 5s. Whenever you see the digit five you will experience it as having a special red colour. Similarly, whenever you see the digit two you will experience it as having a special green colour. I want you to make the special colour as vivid as possible, actually see the colour there. Soon you will be presented with a screen containing both 5’s and 2’s. You will be able to see the 5’s as vividly red and the 2’s as vividly green. On each trial there will be a green shape made up of 2’s. You must select the shape you see. The trials will be presented for one second, two seconds, three seconds or four seconds. Is that clear? Ok we can start”

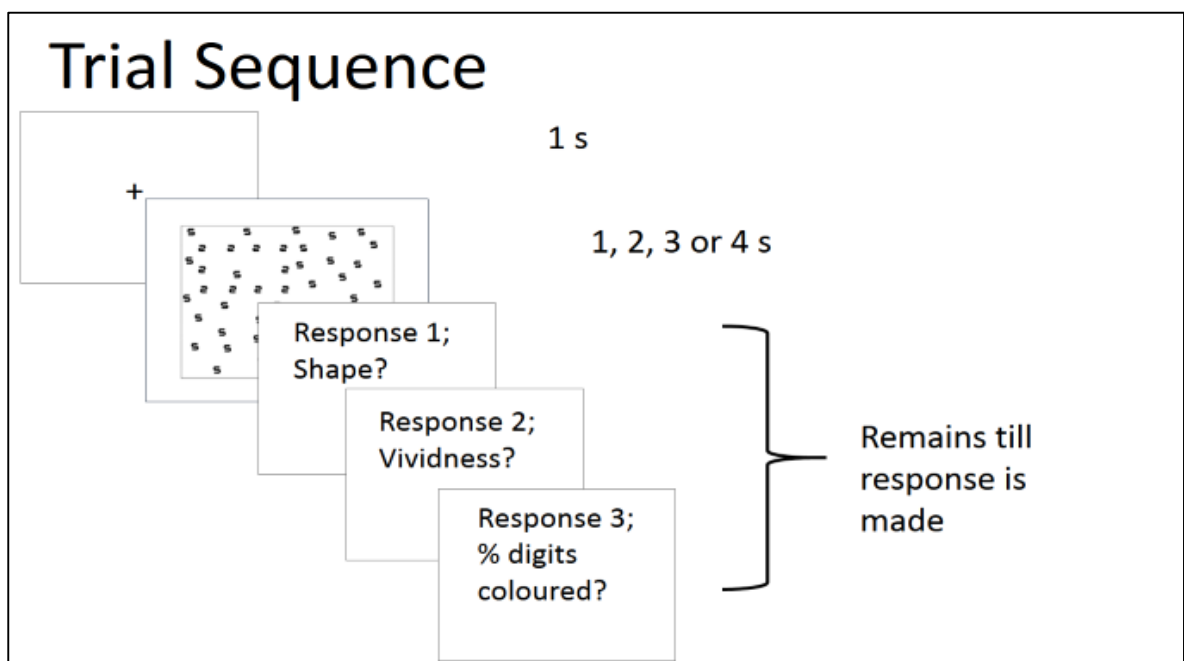


**Figure 2.1.** An example stimulus (A) as presented (in black font), (B) a schematic assuming presentation in colour, and (C) a partially coloured version in line of the phenomenological reports of projector synaesthetes. Note that stimuli were never presented in colour during the experiment.

An example trial was given at the start of each block where they were reminded to find the shape made of 2s, and the responses required. Each trial was preceded by a central fixation cross for 1 second. The stimulus was then displayed for 1, 2, 3 or 4 seconds depending on the block, followed by a blank screen containing instructions to respond using a four-alternative forced choice to indicate the shape (square, rectangle, diamond or triangle). Following this, they were asked to rate their subjective experience of colour during the trial display. Specifically, they were asked to rate the vividness of any perceived colours (1 = no colour, 6 = very vivid colour) followed by the percentage

of digits within the array which were they experienced as coloured. The fixation cross then appeared to signal the start of the next trial. Accuracy was emphasised and participants were aware that the proceeding trial did not begin until a response had been made for the current trial. On completing the hypnosis condition, the suggestion was removed (by stating that numbers no longer had any special colours, and appear as they did before any suggestion was given) then the participant was counted out of hypnosis.

Trial sequence can be seen in Figure 2.2



**Figure 2.2.** Experiment trial sequence. For response 1, shapes (square, rectangle, diamond and triangle) were presented with response keys underneath (keys 1-4).

Response 2, was measured using a six point scale (1 = no colour, 6 = very vivid colour) followed by response 3, the percentage of digits within the array which were coloured which was typed by the participant.

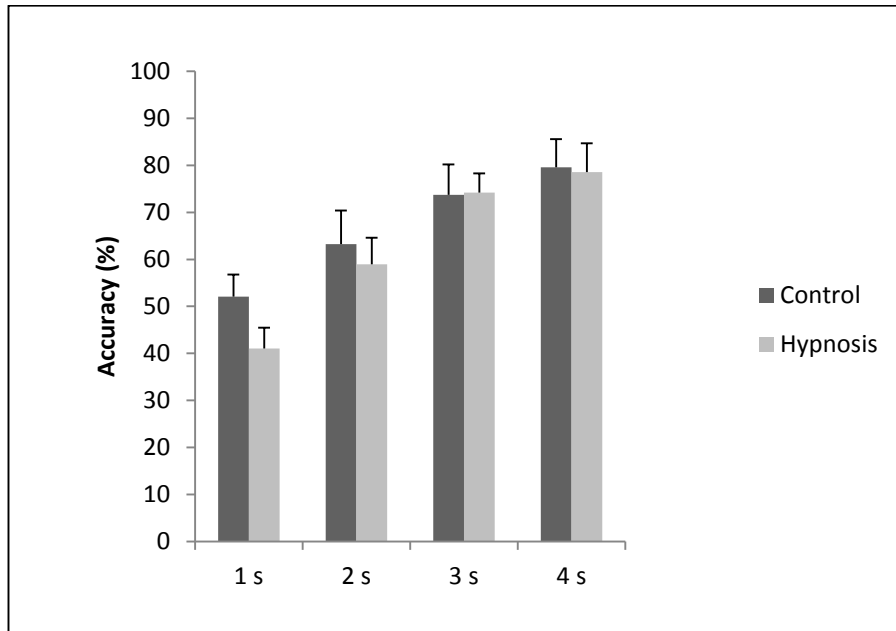


## 2.4 Results

### Accuracy of target detection

The accuracy data were measured using percentage accuracy and were analysed as a 2x4 repeated measures ANOVA contrasting condition (presence/absence of hypnotic suggestion) and duration of stimulus (1-4 seconds). The Greenhouse-Geisser correction was used where appropriate. The main effect of duration was significant ( $F(1.78, 22.13) = 45.16, p < .001$ ) with pairwise comparisons using Bonferroni adjustment showing significant differences between all durations ( $p < .001$ ) other than between 3 and 4 s ( $p = .13$ ) due to accuracy improving when the arrays were presented for longer durations (1 second  $M = 46.6\%$ ,  $MSE = 3.0$ ; 2 seconds  $M = 61.1\%$ ,  $MSE = 4.8$ ; 3 seconds  $M = 74.0\%$ ,  $MSE = 4.5$ ; 4 seconds  $M = 79.1\%$ ,  $MSE = 5.3$ ). The main effect of condition was not significant ( $F(1, 13) = 0.62, p = .45$ ): accuracy for the control condition ( $M = 67.2\%$ ,  $MSE = 5.5$ ) was similar to that in the hypnosis condition ( $M = 63.2\%$ ,  $MSE = 3.9$ ). The interaction was also not significant, with accuracy being similar between control and hypnosis conditions for each duration ( $F(3, 39) = 0.88, p = .46$ ). This data is depicted in Figure 2.3. To determine whether the lack of main effect of condition reflected insensitive data, or supported a null hypothesis, we used a Bayes factor analysis (Dienes, 2011). Whereas significance testing only allows the null hypothesis to be rejected, Bayes factor analysis also allows the null hypothesis to be supported (Kass & Raftery, 1995). If the Bayes factor is less than 1/3 there is substantial evidence for the null over the specified alternative; if greater than 3, substantial evidence for the alternative; otherwise the data are insensitive in distinguishing the two hypotheses. Ward et al. (2010) found that synaesthetes were better than normal on this task by 10%; thus this was used as the standard deviation of a half-normal to represent an alternative hypothesis that the hypnosis suggestion created a genuine synaesthesia (as per the guidelines in Dienes

(2011) Appendix). With an actual mean difference of -4% ( $SE = 5.1\%$ ), the Bayes factor is 0.28, i.e. there was substantial evidence for the null hypothesis, that there is no difference between percentage accuracy for the hypnosis versus control condition.



**Figure 2.3.** Shape detection accuracy for control and hypnosis conditions across stimulus durations (1-4 seconds). Error bars represent 1 SEM.

### Phenomenological reports

We next considered the extent to which the participants experienced colours during the task. Table 2.1 shows the number of trials in which colour was perceived, the average vividness of colours reported by each participant, and the percentage of graphemes in the array that were perceived as coloured. These data are reported only for the hypnotic suggestion condition. Twelve out of the 14 participants experienced some colour during the hypnosis condition. For those who did experience colour, the proportion of digits and intensity in which they saw colour was extremely variable across participants.

**Table 2.1.** Summary of subjective colour experiences for each participant for the hypnosis condition only in descending order from the participant who experienced colour for the most trials to least. The table shows the percentage of trials where a colour was reported, average intensity (1 = no colour, 6 = vivid colour) and percentage of graphemes within the array perceived as coloured.

Part. Number	% Coloured Trials	% of Graphemes Perceived as Coloured (all trials)				Average Intensity (all trials)			
		1 s	2 s	3 s	4 s	1 s	2 s	3 s	4 s
<b>11</b>	100	52	57	49	41	3.96	3.96	3.68	3.79
<b>2</b>	99	63	80	81	81	3.75	5.04	5.04	5.46
<b>8</b>	97	24	37	39	41	2.64	3.57	3.89	4.25
<b>17</b>	97	90	60	56	58	4.32	3.89	3.00	3.07
<b>6</b>	96	37	34	38	42	3.07	3.29	3.32	3.89
<b>12</b>	83	47	61	67	61	3.50	3.89	4.61	3.64
<b>7</b>	81	7	3	6	5	1.50	1.25	1.75	1.50
<b>1</b>	51	29	27	10	1	2.61	2.32	1.54	1.14
<b>16</b>	29	3	7	3	5	1.21	1.39	1.25	1.32
<b>15</b>	14	1	0	2	10	1.11	1.04	1.11	1.29
<b>3</b>	12	7	0	0	0	1.43	1.00	1.00	1.00
<b>14</b>	1	0	0	0	0	1.00	1.04	1.11	1.00
<b>9</b>	0	0	0	0	0	1.00	1.00	1.00	1.00
<b>10</b>	0	0	0	0	0	1.00	1.00	1.00	1.00

A one-way ANOVA comparing intensity ratings across stimulus duration was not significant ( $F(1.45, 18.87) = 0.19, p = .76$ ): that is, intensity ratings were similar across

all durations (1 second  $M = 2.29$ ,  $MSE = 0.33$ ; 2 seconds  $M = 2.41$ ,  $MSE = 0.39$ ; 3 seconds  $M = 2.38$ ,  $MSE = 0.40$ ; 4 seconds  $M = 2.38$ ,  $MSE = 0.42$ ). (Note that Ward et al. (2010), reported a similar average vividness rating, 3, for genuine synaesthetes.) Similarly, a one-way ANOVA comparing percentage of graphemes perceived as coloured across stimulus duration was not significant ( $F(1.52, 19.73) = 0.11$ ,  $p = .84$ ) with comparable percentage of grapheme appearing as coloured across all durations (1 second  $M = 25.72\%$ ,  $MSE = 7.64$ ; 2 seconds  $M = 26.25\%$ ,  $MSE = 7.68$ ; 3 seconds  $M = 24.99\%$ ,  $MSE = 7.72$ ; 4 seconds  $M = 24.75\%$ ,  $MSE = 7.57$ ), (Ward et al. (2010), reported a similar percentage, 30%, for genuine synaesthetes.) The duration which the embedded figures stimulus was presented for therefore did not substantially affect the phenomenological experience of colour.

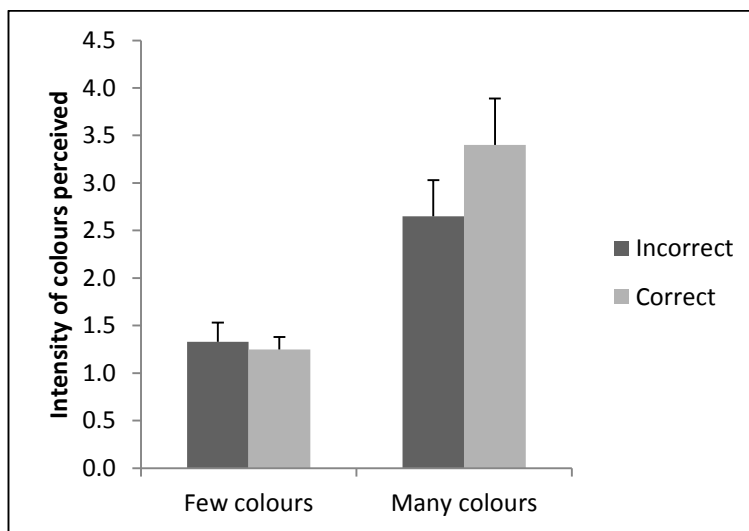
### **Relationship between accuracy and phenomenological reports of colour**

In order to better understand the role, if any, that colour was playing in shape detection the relationship between accuracy and the phenomenological colour reports was explored.

For these analyses, the participants were divided by a median split according to the number of trials in which they reported colour experiences thereby creating two groups: many or few colour response to the colour suggestion.

There is evidence for a relationship between accuracy and phenomenological report when trials are grouped by accuracy. Participant 10 who never experienced colours had 100 % accuracy for the 4 seconds duration block preventing comparison between correct and incorrect trials; after excluding this participant there remained six participants in the group who experienced few colours and seven in the group who experienced many colours. Using phenomenological ratings (mean intensity, mean number of graphemes perceived as coloured) as the dependent variables a  $2 \times 2 \times 4$  ANOVA was conducted contrasting group (many v. few colour-responses), accuracy (correct v. incorrect trials)

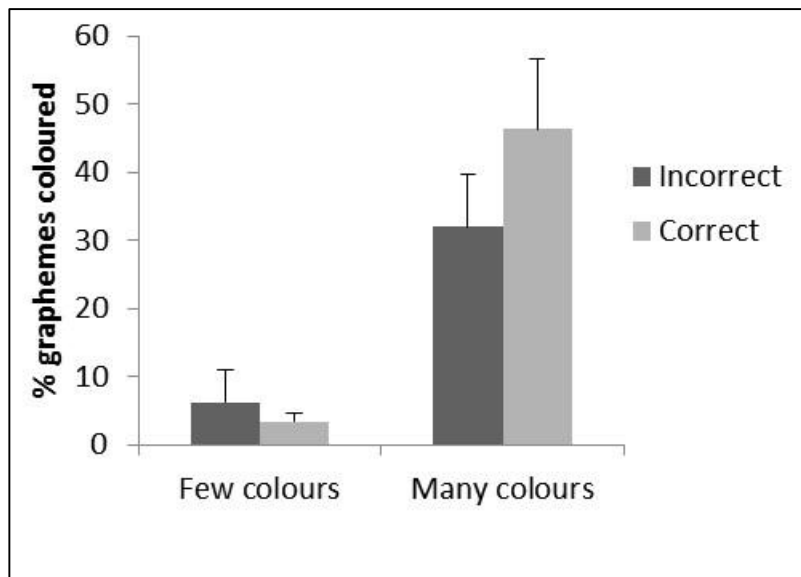
and duration (4 levels). The data are summarised in Figure 3. For intensity, there was a significant interaction of group X accuracy ( $F(1, 11) = 5.09, p = .045$ ). All other main effects and interactions were not significant. The interaction was analysed further by simple effects of accuracy for each group. For the group who experienced few colours, the effect of accuracy was not significant ( $F(1, 5) = .016, p = .71$ ) however for the group who experienced many colours this main effect was significant ( $F(1, 6) = 6.32, p = .046$ ) as more vivid colours were reported for accurate compared to inaccurate trials. This is summarised in Figure 2.4.



**Figure 2.4.** The mean intensity of colours (1 = no colour, 6 = vivid colour) reported for trials in which the embedded figure was correctly or incorrectly detected dependent on whether the participant saw many colours or few colours. Error bars represent 1 SEM.

For the percentage of graphemes perceived as coloured, there was again a significant interaction of group X accuracy ( $F(1, 11) = 5.80, p = .035$ ). The other main effects and interactions were not significant. A simple effects analysis indicated that for the group who experienced few colours, the effect of accuracy was not significant ( $F(1, 5) = 0.51, p = .51$ ) whereas for the group who experienced many colours it was significant

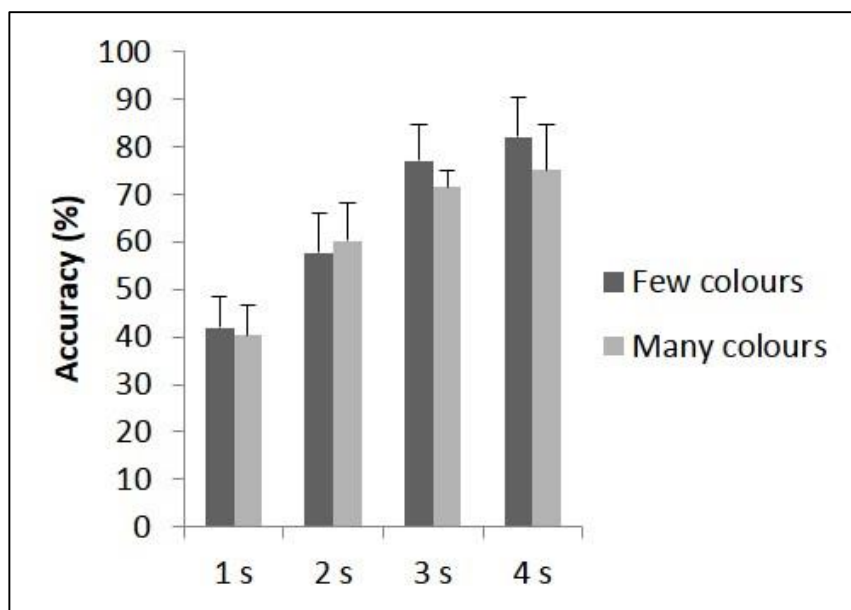
( $F(1, 6) = 6.51, p = .043$ ) with more colours being reported for accurate opposed to inaccurate trials. The data are summarised in Figure 2.5. Together, the results from Figures 2.4 and 2.5 show that participants who saw many colours had more intense and wide spreading phenomenological colour experiences for trials in which they correctly compared to incorrectly identified the embedded shape.



**Figure 2.5.** The percentage of graphemes within the array being reported as coloured for trials in which the embedded figure was correctly or incorrectly perceived. Error bars represent 1 SEM.

Although the different groups report different levels of colour intensity and disparity on correct versus incorrect trials, the overall number of correct trials didn't differ according to these groups. A 2x4 repeated measures ANOVA with percentage correct as the dependent variable contrasting group (experiencing few versus many colours) and duration of stimulus (1-4 seconds) was conducted, considering only the hypnotic-suggestion condition. This data is summarised in Figure 2.6. The main effect of duration was significant ( $F(1.67, 20.09) = 18.88, p < .001$ ) with accuracy improving as stimulus

duration increased. The interaction between group and stimulus durations was not significant ( $F(1.67, 20.09) = 0.31, p = .70$ ). Importantly, the difference in accuracy for the hypnosis block between those who experienced many ( $M = 61.7\%$ ,  $MSE = 5.7$ ) and few ( $M = 64.7\%$ ,  $MSE = 5.7$ ) colour responses to the synaesthesia suggestion was not significant ( $F(1, 12) = 0.13, p = .72$ ). To interpret the non-significant result, a Bayes Factor analysis was conducted. Again a half-normal distribution was chosen to test the alternative hypothesis that the group who experienced many versus few colours performed better, representing a real synaesthesia-like behavioural advantage in those who had phenomenological experience of the colours. As Ward et al. (2010) measured a 10% accuracy advantage for synaesthetes, this was used as the SD. With a mean difference of -3, and MSE of 9.5 the resulting Bayes Factor was 0.58 which is between 1/3 and 3 and therefore indicates insensitive data.



**Figure 2.6.** Shape detection accuracy for lots and little colour responders during the hypnosis condition across stimulus durations (1-4 seconds). Error bars represent 1 SEM.

## 2.5 Discussion

We aimed to determine whether hypnotic synaesthesia was similar either behaviourally or phenomenologically to developmental synaesthesia through measuring accuracy and colour experience during an embedded figures task with and without hypnotic suggestion. Under the hypnotic suggestion the phenomenology of the participants was similar to that documented for synaesthetes. Specifically, they tended not to perceive the entire array of graphemes as coloured and the subjective intensity ratings were similar to those reported by synaesthetes. However, the behavioural advantage previously found for synaesthetes was not found under hypnotic suggestions, even when one only considers those subjects who responded strongly to the specific suggestions. Further analyses (using Bayes factors) suggested that this was not merely due to a lack of sensitivity. As such, our conclusion is that hypnotically induced grapheme-colour experiences are not equivalent to those in developmental synaesthesia.

On first impressions, this result seems at odds with Cohen Kadosh et al. (2009), who found that hypnotically suggested synaesthesia results in similar performance to developmental synaesthetes, showing a deterioration in the ability to detect an achromatic grapheme when the concurrent matched the background colour. However, because this study predicted an impairment (as opposed to an enhancement), their task is potentially more susceptible to demand characteristics. We note that the experimenter in the present study was not blind to the experimental condition. However, the principal effect (if any) of lack of blindness would be to amplify demand characteristics, which we have argued are less likely to apply in our study than in Cohen Kadosh et al. (2009). The combination of a strong behavioural effect in Cohen Kadosh et al., and none at all in our study, is most simply explained by subjects responding according to how they believe they should,



without hypnotically-induced alterations in perceptual abilities. This claim is entirely consistent with subjects in both studies having subjectively compelling experiences.

It is important to note that the ability to respond to the synaesthesia suggestion was very variable across our participants. This is perhaps not surprising since perceptual hallucinations are difficult to evoke even in highly hypnotisable subjects (Bowers, 1998). It should also be noted that many developmental grapheme-colour synaesthetes fail to report colours during this task, at least during brief (1 second) presentations of the array (Ward et al. 2010). The strength of subjective experience of the colours was comparable to that of synaesthetes. Anecdotally, some of our participants noted that the hypnotically suggested colours appeared to diminish over time. To reduce the impact of this, the suggestion was reinforced between blocks to sustain the colours but several participants struggled to maintain the suggestion all the same. Future research should combine extensive training of grapheme-colour pairings (e.g., Rothen, Wantz, & Meier, 2011) with subsequent hypnotic suggestion.

If (at least some) of our hypnotised participants reported colour experiences then why didn't this help them to detect the embedded figure? Our explanation is that the colour hallucinations are primarily added after grapheme (and global figure) identification or, relatedly, that the 'task' of adding colour visualisations competes with the primary task of finding the embedded figure. This is supported by the analysis in which participants were divided (by median split) according to whether they reported many or few colour visualisations. For the half of participants who experienced many colours, significantly more vivid colours were reported for accurate compared to inaccurate trials. This difference was not evident in the group who did not experience much colour, perhaps due to a floor effect given that so little colour was reported by these participants. The enhanced colour experience for correct compared to incorrect trials for

those who did experience colour may reflect the ease with which the colours could be projected onto the graphemes by the participant. In this view, once the shape has been detected, the identity of digits within the array can more easily be inferred, potentially allowing easier visualisation of the spatial localisation of the red and green colours. In trials in which the shape has not been detected, the participant is performing two tasks at once; the conscious task of identifying the shape and the ‘unconscious’ task of projecting colours onto black graphemes. The process of binding the grapheme with the concurrent colour does not seem to occur as automatically in hypnotically suggested synaesthesia, as compared to developmental synaesthesia. Indeed, there is evidence that many hypnotic responses take up capacity by virtue of being hypnotic (Hilgard, 1986; Tobis & Kihlstrom, 2010; Wyzenbeek & Bryant, 2012; contrast Woody & Bowers, 1994). Developmental and artificially induced variants of synaesthesia (ie. hypnotic or drug induced) may be different. Auvray and Farina (in press) have explored this issue, and using their characterisation of developmental synaesthesia (as satisfying the criteria of the pairing of an inducer with a conscious concurrent, the idiosyncratic nature of the concurrent, and the concurrent being produced automatically and consistently) they have suggested hypnotic synaesthesia satisfies the requirements of having a concurrent paired with an inducer, in an idiosyncratic and automatic way, but that consistency requires further investigation. Further, they suggest that the concurrent may be produced by imagery. Our results support a limited similarity between developmental and hypnotic synaesthesia, and showing that despite the phenomenology, the concurrent may not be automatically produced (as shown by a lack of behavioural improvement).

How is it possible that our participants were able to generate colour experiences at all (assuming, that is, that their subjective reports had some basis)? One possibility is that it relies on mechanisms normally used to support visual imagery. However, we did

not assess this directly in our research. Other research suggests that there are individual differences between high and low hypnotisable subjects in the tendency to employ imagery in suitable contexts (e.g. Lynn, & Green, 2011; Hilgard, 1979; Roche & McConkey, 1990; Tellegen & Atkinson, 1974; Wilson & Barber, 1982). However, the tendency to employ imagery in certain contexts may reflect strategic differences rather than ability differences given that high susceptible participants are not especially quick at visual information processing (Acosta & Crawford, 1985; Friedman, Taub, Sturr, & Monty, 1987) and are not especially high in rated imagery vividness (Jamieson & Sheehan, 2002; though compare the feats of imagery achieved by high but not low susceptible subjects in Mazzoni et al., 2009). These suggestions are tentative given that we did not run low hypnotisable subjects. Further, measuring the mental imagery abilities of participants would help clarify to what extent participants are able to use mental imagery to complete the tasks and how this relates to the individual profiles of hypnotic susceptibility (Cardeña, 2005; Terhune & Cardeña, 2010).

The lack of behavioural advantage for hypnotic synaesthetes can be taken as evidence against functional similarity between hypnotic and natural synaesthesia, but by the same token it provides support for the Cold Control theory of hypnosis (Dienes & Perner, 2007), and the class of theories which postulate no special ability is gained when an action is performed hypnotically (e.g. Kirsch & Lynn, 1999). Cold Control theory states that the subjective lack of volition in hypnosis is due to not forming the higher order thought (HOT) linked to the intention. In this sense, someone who responds to the suggestion ‘lift your arm’ could lift their arm but not have the HOT ‘I am intending to my arm’. If this theory holds, then participants should not be able to perform better in the hypnosis block than they do in the control block. Our data indeed support this inference. Theories that postulate that hypnotic hallucination is perception-like in a way that goes

beyond normal imagery (e.g. Brown & Oakley, 2004) are challenged by the current results.

In summary, hypnosis can induce verbal reports of phenomenological experience of grapheme-colour synaesthesia similar to those provided by developmental grapheme-colour synaesthetes, when applied in high susceptible participants. However, even though there are strong similarities in the subjective reports of natural and hypnotic synaesthetes, this is not reflected in behavioural similarities. Highly hypnotisable subjects do not gain any perpetual abilities with a hypnotic suggestion that they did not have prior to hypnotic induction (Dienes & Perner, 2007).

**CHAPTER 3:****HYPNOTIC MOTION-SOUND SYNAESTHESIA AND MENTAL IMAGERY****-PAPER 2****3.1 Abstract**

Motion-sound (MS) synaesthesia occurs when viewing movement or flashes of light causes a concurrent auditory experience. In general, rhythms are easier to discriminate when presented via audition (sequences of beeps) rather than vision (sequences of flashes), and previous research has shown a behavioural advantage for MS synaesthetes when discriminating pairs of flashing light sequences. This is consistent with the idea that the flashes have auditory-like properties for these people. To explore this further, we took advantage of the fact that hypnosis can create perceptual experiences reported to be phenomenologically similar to the experiences of synaesthetes. We asked whether behavioural advantages similar to those measured in MS synaesthetes can be evoked in participants using mental imagery or hypnosis to “hear” beeps similar to Morse code when viewing flashing circles. MS synaesthetes were significantly better at differentiating visual trials compared to low (hypnosis) susceptible participants. Mental imagery or hypnosis didn’t improve the accuracy of participants, therefore MS synaesthesia appears to involve more than automatic mental imagery and can’t be created using hypnosis.

### 3.2 Introduction

Motion-sound (MS) synaesthesia is one of the more recently discovered types of synaesthesia and is characterised by objective visual movement or flashes of light (inducer) causing a simultaneous sound experience (concurrent) (Saenz & Koch, 2008). There is variability in the sounds which different MS synaesthetes hear (whirring, beeps, tapping) (Saenz & Koch, 2008), however the only published study of motion-hearing synaesthesia tested four synaesthetes who all heard beeps similar to Morse code when viewing flashing circles of light (Saenz & Koch, 2008). When making same/different judgements for pairs of visual or auditory sequences, there is a general behavioural advantage when determining whether auditory sequences are the same or not, compared to visual sequences (Glenberg, Mann, Altman, Forman, & Procise, 1989; Guttman, Gilroy, & Blake, 2005). Participants are able to hear the “rhythm” of the beeps easier than viewing the sequence of flashing circles. Saenz and Koch (2008) therefore hypothesised that MS synaesthetes would have a behavioural advantage over non-synaesthetes for pairs of visual sequences in virtue of the concurrent sound, but that there would be no difference between synaesthetes and non-synaesthetes when discriminating among purely auditory sequences. This is indeed what they found, and this was provided as evidence for the existence of MS synaesthesia. This doesn’t however inform us whether non-MS synaesthetes can improve their accuracy if they deliberately hear similar sounds. In this study we shall explore artificial MS synaesthesia using mental imagery and hypnosis to ask whether similar behavioural advantages to developmental MS synaesthetes can be created and are not therefore special to MS synaesthetes. This would show that MS synaesthesia is due to specific cognitions rather than of organic origin. By exploring the phenomenology of developmental MS synaesthetes this study also considers how MS synaesthesia compares to general synaesthesia classification systems. This is required as automaticity is the only criteria explored thus far.

The first study of MS synaesthesia supported the automatic nature of the concurrent sound, however this only illustrates one possible criterion for synaesthesia (Auvray & Farina, in press). There are difficulties in defining synaesthesia due to the large, increasing number of synaesthesia types claimed as well as selection biases of participants in synaesthesia experiments (Simner, 2012). Auvray and Farina suggest four distinct criteria that should be satisfied for a particular experience to be classified as synaesthesia-like or synaesthetic. These are; pairing between an inducer and a conscious concurrent, idiosyncratic concurrents, automaticity and consistency. The auditory and visual sequence task used by Saenz and Koch (2008) showed that the inducer (movement) was paired with a conscious concurrent (consciously perceived sound). Further to this, the auditory concurrent was automatic as the MS synaesthetes had a behavioural advantage for the visual trials in comparison to control participants.

The other aspects of Auvray and Farina's synaesthesia classification system have not yet been explored for MS synaesthesia, that of consistency and idiosyncrasy. Consistency is typically measured in synaesthesia through test re-test consistency, where the concurrents evoked by specific inducers are indicated by the synaesthete either several times in the same session (Eagleman et al., 2007) or after a delay in time such as months (Simner, Gärtnner, & Taylor, 2011). Idiosyncrasy is individuality in specific inducer and concurrent pairings. Not all synaesthetes have the same experience for a particular inducer (such as what colour grapheme-colour synaesthetes experience for the letter "Y"). Saenz and Koch (2008) noted that the phenomenology of MS synaesthesia for their four synaesthetes consisted of non-linguistic sounds like beeps, whirrs or taps. How idiosyncratic are these sounds? In comparison to a letter having a particular colour, it could be argued that all these sounds (beeps, whirrs or taps) are associated with particular movements or flashes of light. More unusual sounds triggered by movement would

provide evidence for idiosyncrasy in MS synaesthesia. Furthermore, do different types of movement make different sounds? Saenz and Koch (2009) noted that the synaesthetes reported having these sounds for as long as they could remember, however there are no test, re-test measures of MS synaesthesia. Consistency is therefore not known. Exploring these aspects of MS synaesthesia would show how it compares to other more researched types of synaesthesia. There is however debate whether consistency is really a requirement of synaesthesia, or whether consistent concurrents are limited to a subset of synaesthetes (Simner, 2012).

Although Saenz and Koch (2008) have shown that MS synaesthesia gives a behavioural advantage for distinguishing between visual sequences pairs in relation to controls, the role of mental imagery in this context has not been explored. Could mental imagery alone produce the same advantage with the auditory concurrents working as an “auditory technique”? If so, this would show that MS synaesthesia is due to functional rather than organic mechanisms.

Hypnosis allows a participant’s perceptual experience to be altered in a specific way, such as to create a visual hallucination of not seeing something which has been presented in front of them (Bowers, 1998). Generally, hypnosis starts with an induction where the participant is brought into a relaxed state, before the experimenter makes structured suggestions (Oakley & Halligan, 2009). If the suggestions are tested at this point during hypnosis, they are hypnotic suggestions. Participants are then brought out of hypnosis after which post-hypnotic (out of hypnosis) suggestions can be tested, such as analgesia. Post-hypnotic suggestions allow the testing of participants while they are in an alert state.



The scope of hypnosis to generate new experiences can be used to research theories of hypnosis itself. One group of theories pertain that hypnosis can be used to create new abilities or skills in the participant that are not accessible without hypnosis, such as being able to withstand pain (Hilgard, 1986; Freeman, Barabasz, Barabasz, & Warner, 2000) or control automatic cognitive processes such as font colour and colour word binding in the Stroop task (Raz et al., 2003; Raz, Shapiro, Fan, & Posner, 2002). Another class of theories maintain hypnosis can't create any new abilities (eg. Sarbin and Coe, 1972; Spanos, 1986). Theories with this view include higher order thought (HOT) theories (Dienes & Perner, 2007), which suggest hypnosis works by impeding the higher order thought associated with a particular act, for example lifting your arm with a levitating suggestion, but without thinking "I am intending to lift my arm", causing a feeling of loss of control for the action. Hypnosis is an alteration in meta-cognition, not creation of new abilities. Therefore, if hypnosis can create new abilities, such as task advantages similar to those exhibited by developmental synaesthetes, this would support theories which sustain new abilities can be created, otherwise they would support the latter.

Hypnosis has been used previously in an attempt to create hypnotic grapheme-colour (GC) synaesthesia. Cohen Kadosh and colleagues investigated whether grapheme-colour synaesthesia-like percepts could be induced in participants highly susceptible to hypnosis, and whether this was sufficient to create associated behavioural changes (Cohen Kadosh, Henik, Catena, et al., 2009). For hypnotic synaesthetes, accuracy was significantly lower for detecting graphemes when the concurrent and background colour matched, making them harder to see compared to when they didn't. This was interpreted as support for the view that synaesthesia-like behaviour was created without organic

changes (as there would have been insufficient time following hypnosis to generate neurological changes).

Anderson et al. (2014) examined a situation in which hypnotically-induced GC synaesthesia would be expected to induce behavioural advantages (rather than impairments). Participants were required to detect an embedded shape, rate the vividness of colours experienced and the percentage of digits in the array which appeared coloured. Accuracy for identifying the embedded shape was not higher for the hypnosis block (in which they experienced colours for the digits) in comparison to the no suggestion control block. This was in contrast to studies which have tested developmental GC synaesthetes on the same task (Ward et al., 2010). The authors suggested that the colours experienced were more akin to mental imagery than true synaesthesia. This is because the colours did not appear automatically and therefore aid in the shape detection task, they were produced after shape detection (when it was easier to add colour to the image as the location of the shape had already been identified and it was clear which colour should appear where within the digit array). They therefore suggested that hypnotic GC synaesthesia was similar phenomenologically, but not behaviourally. Results of hypnotic synaesthesia studies are therefore inconsistent thus far.

Dissociation is either a sense of detachment, in respect to yourself or your environment, or compartmentalisation, an impairment in a usually controllable process (Holmes et al., 2005). There have been some reports that people who are highly susceptible to hypnosis and generally do not experience dissociation become more dissociative while “under” hypnosis (Terhune et al., 2011) although the general trend for highs to be dissociative is disputable (Dienes et al., 2009). This study will therefore use post-hypnotic suggestion (where the suggestion is triggered after the participants has been brought out of hypnosis) to prevent any possible confounding effects of a hypnotic-

suggestion (where the suggestion is triggered whilst the participant is under hypnosis). Further to this, participants will complete a dissociation questionnaire, the Dissociative Experiences Scale- C (DES-C) (Wright & Loftus, 1999) to determine whether dissociation is accounting for behavioural changes in participants.

The current study will therefore use the auditory and visual sequence differentiation task used by Saenz and Koch (2009) and compare task performance for developmental MS synaesthetes and control participants of different hypnotic susceptibilities. Mental imagery instructions or post-hypnotic suggestions will be given for control participants to use the auditory technique in the attempt to improve their accuracy for visual trials in a similar manner to the developmental MS synaesthetes. Questionnaires will be used to assess their visual and auditory mental imagery abilities and dissociation.

### 3.3 Method

For this study all participants completed the task at *baseline* i.e., participants completed it without any mental imagery or hypnotic instruction to measure their general ability. The non-MS synaesthetes completed the task a second *experimental* time to investigate the effects of mental imagery or hypnotic instruction. A mixed two (time; baseline or experimental) by four (group; high, medium, low or MS synaesthete) design was used with repeated measures for the time and independent for condition.

#### Participants

Eleven men, 32 women and one transgender (N = 44) participant aged 18-44 ( $M = 23.49$ ,  $SD = 5.40$ ) completed the experiment. They were recruited through the University of Sussex hypnotic susceptibility database and synaesthesia database. They were paid £5 for participation. Ethical clearance was granted by the University of Sussex Ethics

Committee. There were 16 low susceptible, 10 medium susceptible, 14 high susceptible, 3 MS synaesthetes who hear beeps for flashing lights, and one MS synaesthete with other MS concurrents. As he had very different sounds he was not included in the MS synaesthete group.

Participant CT hears crackles similar to lightening when viewing flashing lights, very different to those of the other synaesthetes therefore he was not included in the general analysis. He is also highly susceptible to hypnosis, therefore we tested whether we could create auditory hallucinations similar to the other high participants. Even though he had his own specific concurrent to the flashing lights (which happened for roughly 40% of trials), after post-hypnotic suggestion, he actually heard beeps as well (for an additional 10% of trials). This avenue is not explored further in this study, but the ability to add a secondary concurrent in a synaesthete could allow comparison of developmental and artificial concurrents in the same individual in future research.

## **Materials**

Auditory sequences were played through Sennheiser HD 497 headphones. The program was run using E-prime 2.0 and presented on a 32cm CRT monitor with 60 Hz refresh rate.

The Vividness of Visual Imagery Questionnaire (VVIQ; Marks & Marks, 1973) and Clarity of Auditory Imagery Scale (CAIS; Willander & Baraldi, 2010) were used to measure the visual and auditory mental imagery capabilities respectively. Dissociation was measured using the Dissociative Experiences Scale-Comparison (DES-C; Wright, Loftus, & Wright, 2002).

## Procedure

Participants sat with their chin on a rest, 44.5 cm from the monitor. The experiment was based on the Saenz and Koch (2008) study. Each sequence was made of four short (50ms) and four long (200ms) presentations of beeps (360Hz) or white circles (1.5 degree radius) each separated by a 100ms blank interval. This series of beeps/ flashing circles made a short sequence, similar to Morse code. In each trial, two sequences would be presented in succession which were either identical to each other, or slightly different. Each trial consisted of either two auditory ‘beep’ sequences or two white flashing circles sequences. During auditory trials, only a fixation cross was on screen. There were 100 trials (50 visual, 50 auditory) and half the stimulus pairs were the same. Participants made a 2AFC decision using the keyboard to indicate whether the pair of sequences were the same, or different (S = same, D = different). Initially four practice trials were completed during which feedback was not given before the main experiment started. Participants were informed that they would complete the experiment twice with different instructions before the second run and knew whether they were in the hypnosis (high hypnotic susceptibility) or mental imagery (low or medium hypnotic susceptibility) group. The three MS synaesthetes completed the task once (other than the highly hypnotisable MS synaesthete who completed it twice). The experiment was conducted in a darkened room.

After the baseline block where the general ability of the participant was recorded, instructions for the experimental block were given to the low, medium and high groups (MS synaesthetes didn’t complete the experimental block as they already have an auditory concurrent). Those in the hypnosis group were given a short induction before a post-hypnotic suggestion to hear a beep every time a white circle appeared on the screen, and to hear these beeps in the same sequence in which the flashing circles

appeared. This would be triggered by one clap of the hands, with two claps indicating the end of the suggestion. They were then brought out of hypnosis. The mental imagery group only read the suggestion and trigger instruction (hand clap), but not the hypnotic induction. This ensured that both (non synaesthetic) groups were given the same instructions. The experimenter then clapped their hands once before the experiment was completed for the second time to trigger the post-hypnotic or mental imagery suggestion to hear a concurrent auditory experience for the flashing white circles.

After the experimental block the experimenter clapped their hands twice to stop the post-hypnotic suggestion (or indicate that the participant could stop deliberately imagining the sounds). Participants were asked whether they used any techniques to aid in the differentiation of the sequences (baseline or experimental block; visual or auditory sequences). They answered additional questions about the experimental block; % of visual trials they heard beeps for and how many years of music experience they had. Finally, the VVIQ, CAIS and DES-C were administered.

### 3.4 Results

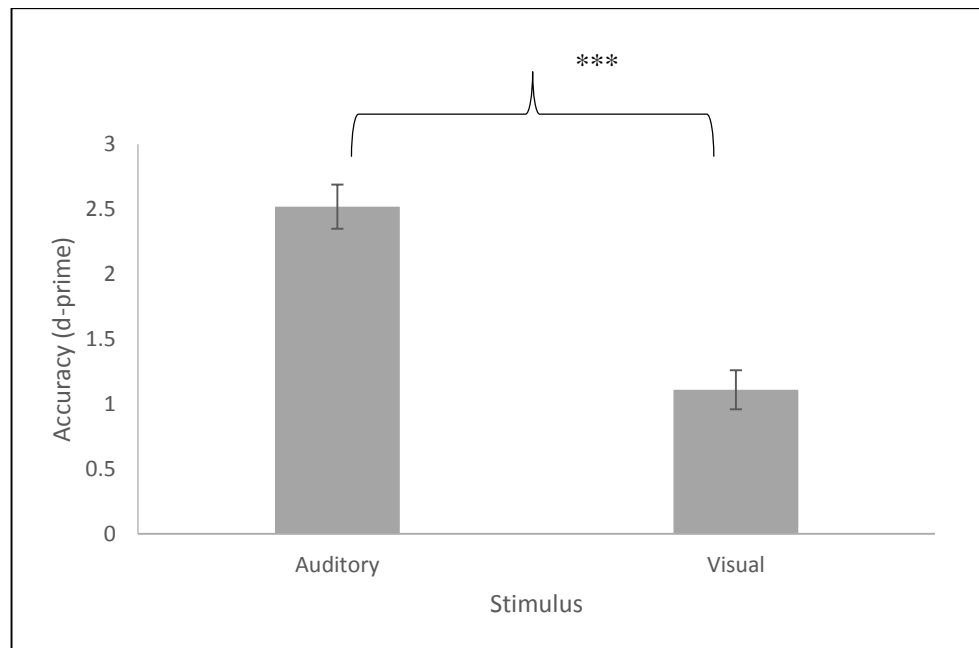
The analyses will be conducted in two stages. Initially, the baseline data (completion of the experiment initially with no mental imagery or hypnotic instruction) will be analysed according to *status* i.e. susceptibility or MS synaesthete. Next, the experimental data (completion of the experiment after mental imagery or hypnotic instruction) will be analysed according to *condition* i.e., mental imagery or hypnotic suggestion.

Accuracy was compared using  $d'$ , this measure of accuracy represents the difference between the standardised (z score) signal present, and signal absent data distributions. The task used in this study was to decide whether two sequences were the

same or different. A hit (H) corresponded to a trial in which a different pair of sequences were correctly classed as different by the participant, and a false alarm (FA) corresponded to a trial in which two same sequences were incorrectly classed as different. The formula is  $d' = z(H) - z(FA)$ . Response bias, how the participants are tending to respond, was also analysed to see if this accounts for differences between groups. The measure of response bias used with  $d'$  is Criterion,  $c = -(Z(H) + Z(FA))/2$ . Larger values indicate a bias towards one particular response. A negative criterion value suggests a greater number of “different” responses (liberal bias). Positive criterion values show a greater number of “same” responses (conservative bias).

### **Baseline accuracy**

We first tested whether accuracy for auditory trials was greater than for visual trials, as this is the premise on which the study is based. If auditory trials were not easier to distinguish between, then advantages from internal auditory concurrents in MS synaesthetes would not aid in differentiation for visual trials. We performed a two (stimulus; visual or auditory) by four (group; low hypnotisability, medium hypnotisability, high hypnotisability or MS synaesthete) mixed ANOVA with repeated measures for stimulus, with  $d'$  as the dependent variable. The main effect of stimulus when ignoring time or group was significant ( $F(1, 39) = 83.45, p < .001$ ) with accuracy of auditory trials being higher than that of visual trials (see Figure 3.1). This showed that the basic principle underlying the study was upheld, allowing condition dependent behavioural improvements for visual trials compared to auditory trials to be compared.

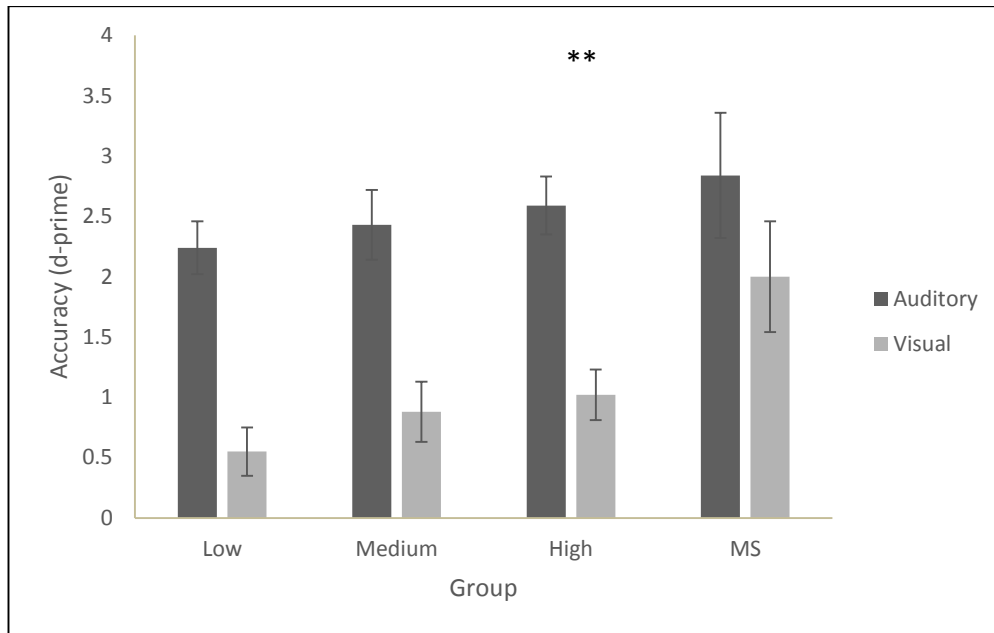


**Figure 3.1.** Accuracy for auditory or visual trials at baseline, while ignoring group.

Error bars represent +/- 1SEM.

Next, differences between the groups at baseline was tested. The main effect of group when ignoring stimulus was not significant ( $F(3, 39) = 1.91, p = .14$ ) with low, medium and high susceptible participants having similar accuracy to MS synaesthetes overall. This shows that there were no general differences in task ability between the groups. The interaction between group and stimulus was also not significant ( $F(3, 39) = 0.92, p = .44$ ) showing that the relationship between accuracy for auditory and visual trials was the same across all groups as can be seen in Figure 3.2.





**Figure 3.2.** Accuracy ( $d'$ ) of low, medium and high susceptibility participants and MS synaesthetes for visual and auditory trials in the baseline block. Error bars represent  $\pm 1$ SEM.

We wanted to determine whether there was a trend for differences between groups in the data. We therefore conducted one way ANOVAs on each stimulus individually. First a four (group; low hypnotisability, medium hypnotisability, high hypnotisability or MS synaesthete) way independent ANOVA was run for auditory trials. The main effect of group was not significant ( $F(3, 39) = 0.59, p = .633$ ) with similar accuracy across all four groups as summarised in Figure 3.2. All groups showed the same skill for auditory trials.

We next tested whether MS synaesthetes could distinguish between visual trials better than non- MS synaesthetes, as predicted on the basis of previous literature (Saenz

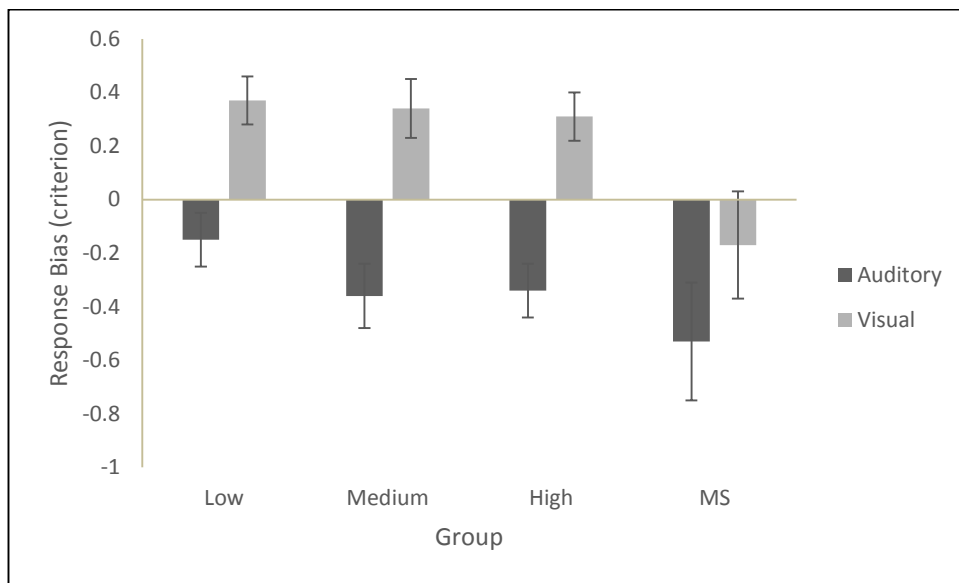
& Koch, 2008). To investigate whether there was a difference in accuracy for visual trials, a four (group; low hypnotisability, medium hypnotisability, high hypnotisability or MS synaesthete) way independent ANOVA was conducted. The main effect of group was significant ( $F(3, 39) = 3.07, p = .04$ ) and Bonferroni adjusted post-hoc comparisons found significantly higher accuracy for MS synaesthetes compared to low susceptibility participants ( $p = .04$ ), but no differences between any other groups. MS synaesthetes had the greatest accuracy for distinguishing between visual trials, as seen in Figure 3.2, however there also appears to be a slight trend for higher susceptibility to be associated with greater accuracy on this task even though this is a baseline measure before any suggestion has been given.

### **Baseline response bias**

Next we tested whether there were differences in how the participants answered. For example, were the low group less accurate because they tended to respond same for visual trials because they were less sensitive to differences? A negative criterion value reflects a liberal bias, that is a greater number of “different” responses indicating a bias towards choosing the response “different” in the task. Positive criterion values show a conservative bias, that is a greater number of “same” responses and a bias towards choosing the response “same” in the task. In order to determine whether there were differences in how participants answered a two (stimulus; visual or auditory) by four (group; low hypnotisability, medium hypnotisability, high hypnotisability or MS synaesthete) mixed ANOVA with repeated measures for stimulus was conducted with  $d'$  criterion as the dependent variable.

We have already shown that accuracy was significantly higher overall for auditory compared to visual trials. Now looking at criterion, the main effect of stimulus

when ignoring group was significant ( $F(1, 39) = 37.15, p < .001$ ) with participants being more likely to respond “different” for auditory trials and “same” for visual trials. One sample t-tests confirmed that these biases were significantly different from zero ( $t(43) = -5.00, p < .001$ ;  $t(43) = 5.26, p < .001$  respectively). There were therefore significant differences in how the participants responded depending on the type of trial. The data is shown in Figure 3.3.



**Figure 3.3.** Response bias of low, medium and high susceptibility participants and MS synaesthetes for visual and auditory trials in the baseline block. Negative values reflect a greater number of “different” responses (liberal bias). Positive values show a greater number of “same” responses (conservative bias). Error bars represent  $\pm 1$ SEM.

Were there differences between the groups in how they responded? The main effect of group when ignoring stimulus was not significant ( $F(3, 39) = 2.48, p = .08$ ) with relatively consistent responses across all groups. The interaction was not significant ( $F(3, 39) = 0.62, p = .61$ ). Therefore the relationship between criterion and

trial type was similar across groups. We wanted to look for trends, therefore the data were split according to stimulus type.

Initially a four (group; low hypnotisability, medium hypnotisability, high hypnotisability or MS synaesthete) way independent ANOVA was run for auditory trials to see if all groups responses in the same way. The main effect of group was not significant ( $F(3, 39) = 1.30, p = .29$ ) with similar criterion across all four groups. Therefore all groups not only had the same level of accuracy for auditory trials, but they responded in the same way as well.

To investigate whether there was a difference for visual trials, a four (group; low hypnotisability, medium hypnotisability, high hypnotisability or MS synaesthete) way independent ANOVA was conducted. The main effect of group was not significant ( $F(3, 39) = 2.11, p = .11$ ) as responses type was similar across groups, although there was a general trend for MS synaesthetes to respond more as “different”. The MS synaesthetes, who were significantly more accurate than low susceptible participants on visual trials, tended to respond “different” more which is in line with the general response bias of all participants to respond “different” for auditory trials. This could be interpreted as further evidence of the MS synaesthetes actually hearing sounds when viewing the flashing circles.

### **Spontaneous baseline strategies**

Non-MS synaesthetes (high, medium and low susceptible participants) were asked after completing the experiment whether they used any strategies to aid their judgements the first time they completed the experiment for auditory trials, or for visual trials. People generally just listened to the auditory trials, which is not surprising since there is a general advantage for auditory sequence differentiation. However, 15 of the non-

synaesthetes (7 low, 7 medium and 1 high) used mentally created “beeps”, which were described as similar to the actual beeps they heard during the auditory trials, to aid their judgements for the visual trials. They spontaneously used the same strategy as the MS synaesthetes, and this was before MS synaesthesia, or the suggestion, had been mentioned to them. In order to determine whether this produced a behavioural improvement compared to participants who did not add the beeps to visual trials themselves, an independent samples Mann-Whitney U test comparing accuracy for visual trials in the baseline block, ignoring the group of participant was conducted, revealing no significant difference ( $U = 235.00$ ,  $p = .18$ ,  $r = .21$ ) between the groups (no beeps, *Median* = 0.47, *range* = -0.59-3.73; yes beeps, *Median* = 0.94, *range* = -0.10-1.53). When non-MS synaesthetic participants spontaneously used mentally evoked beeps to help them differentiate between visual trials in the baseline block, this did not actually improve their accuracy.

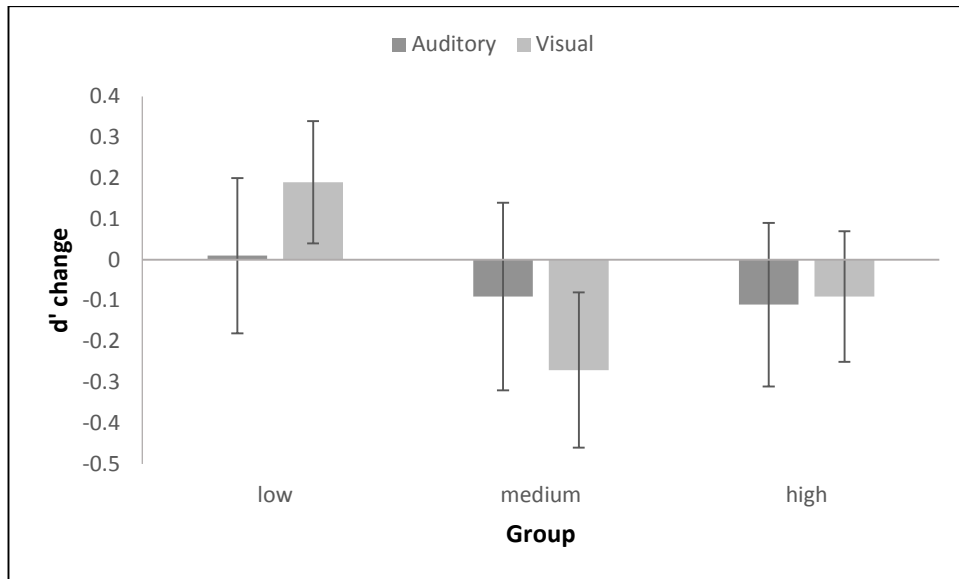
### **Effect of mental imagery or post- hypnotic suggestion on accuracy**

Spontaneously using beeps for visual trials did not cause those participants to have better accuracy. In order to determine whether hypnotic suggestion, or mental imagery, improved performance for non-MS synaesthetes, the difference between baseline and experimental conditions was compared. A change score was calculated for each participant by subtracting the baseline accuracy or criterion value from the experimental block value for visual or auditory trials.

Initially a two (stimulus; visual or auditory) by three way (group; low, medium or high hypnotisability) mixed ANOVA with repeated measures for stimulus was run with  $d'$  as the dependent variable. The low and medium groups received mental imagery instructions, whereas the high group received hypnotic suggestion. The low and

medium groups were not combined, as in the Anderson et al. (2014) study of hypnotic synaesthesia as the high susceptible participants performed comparably to GC synaesthetes suggesting a link between susceptibility and task performance. The key statistics of interest in the current study is whether visual accuracy increases as a result of hypnotic suggestion and imagery suggestion (a main effect of stimulus) or whether an increase in visual scores is found for hypnotic suggestion alone (an interaction of stimulus and group such that 'highs' show the greatest improvement on visual trials). The main effect of stimulus when ignoring group was not significant ( $F(1, 37) = 0.00, p = .98$ ) with accuracy change of auditory trials being similar to visual trials therefore there was not an overall improvement for one stimulus type in comparison to the other. The main effect of group when ignoring stimulus was not significant ( $F(2, 37) = 0.94, p = .40$ ), with similar overall accuracy change across all groups. The interaction was also not significant ( $F(2, 37) = 0.57, p = .57$ ). The relationship between accuracy change for stimuli was similar across all groups and can be seen in Figure 3.4.

Finally for accuracy change, the data was split by stimulus type. A one way between subjects ANOVA was conducted on the auditory trials, with no significant difference ( $F(2, 37) = 0.11, p = .90$ ) between the different susceptibility groups. For visual trials, no significant difference ( $F(2, 37) = 1.86, p = .17$ ) between the different susceptibility groups was evident therefore there was no difference between the effects of mental imagery or post-hypnotic suggestion. As can be seen in Figure 3.4, the only increase in accuracy was for the low group in visual trials. This could possibly be a practice effect given that this group started with the worst performance. In general, from looking at Figure 3.4 it appears that performance was relatively stable across the baseline and experimental blocks.



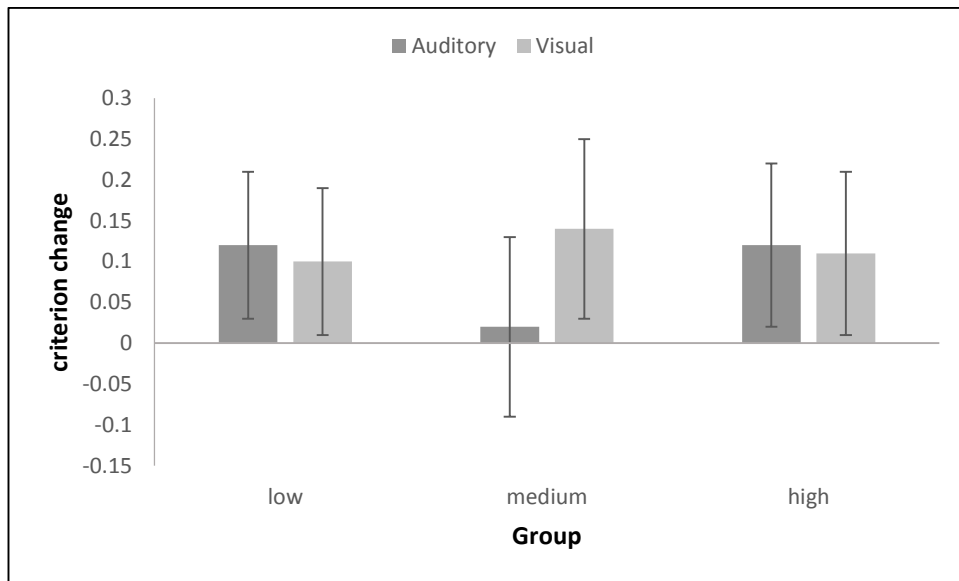
**Figure 3.4.** Accuracy ( $d'$ ) change for low, medium and high susceptible groups. Error bars represent  $\pm 1$  SEM.

### Effect of mental imagery or post- hypnotic suggestion on response bias

No changes in accuracy were evident as a result of mental imagery or post-hypnotic suggestion, however this does not rule out changes in response bias. A two (stimulus; visual or auditory) by three (group; low hypnotisability, medium hypnotisability or high hypnotisability) way mixed ANOVA with repeated measures for stimulus was run with criterion as the dependent variable. For response bias, the main effect of stimulus was not significant ( $F(1, 37) = 0.17, p = .68$ ) with similarly little response change for auditory and visual trials. The main effect of group was not significant ( $F(2, 37) = 0.05, p = .95$ ) with overall bias being similar across groups. The interaction was not significant ( $F(2, 37) = 0.31, p = .73$ ) and can be seen in Figure 3.5.

The data was then split according to stimulus type, and a one way ANOVA for group conducted on response change initially for auditory, then visual trials. For

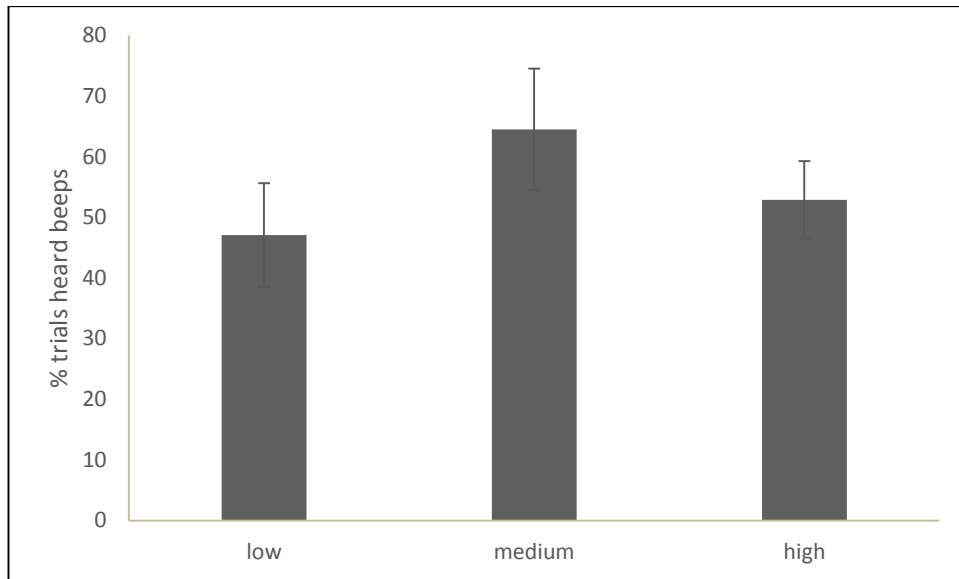
auditory trials, the main effect of group was not significant ( $F(2, 37) = 0.27, p = .78$ ) with similarly small changes in response type across groups. For visual trials, there was also no significant difference ( $F(2, 37) = 0.03, p = .97$ ) with similar response change across groups. Giving non-MS synaesthetes mental imagery or post-hypnotic suggestion therefore didn't improve accuracy for visual trials or change how they responded.



**Figure 3.5.** Response bias change for low, medium and high susceptible participants for auditory and visual trials. Error bars represent  $\pm 1$ SEM.

To confirm that non-MS participants were actually hearing beeps for the flashing circles, and test whether there were differences between the number of beeps heard depending on group, a three (group; low, medium or high susceptible) way independent ANOVA was conducted on the percentage of trials for which beeps were heard. The number of beeps was similar across groups ( $F(2, 37) = 1.02, p = .37$ ) as can be seen in Figure 3.6. All groups did hear beeps for the visual trials in around half the trials.





**Figure 3.6.** Percentage of visual trials which auditory beeps were heard for in low, medium and high susceptible participants. Error bars represent  $\pm 1$  SEM.

### Correlations with questionnaire measures

Exploratory correlational analysis was carried out between the different experimental measures and the questionnaires completed after the experiment for the 40 non-MS synaesthete participants. This can be seen in Table 3.1.

If it was the sound of the beeps themselves which aids in the visual sequence differentiation for MS synaesthetes, we would expect the number of trials for which beeps were heard to significantly correlate with visual  $d'$  which was not found. The general trend of higher hypnotisability participants being more accurate was not significant. None of the mental imagery measures correlated to the visual trial accuracy. Hearing beeps appeared to not actually improve the participant's performance suggesting that the advantage of MS synaesthetes is due to more than the

phenomenology of the sound. Years of musical experience was the only measure which was significantly correlated to visual accuracy.

**Table 3.1.** Spearman's Rho correlations between behavioural measures for the experimental block (non-MS synaesthetes) ignoring group against post-experiment questionnaire responses.

	Visual criterion	Auditory d'	Auditory criterion	WS	VVIQ	Auditory Imagery	DESC	% beeps for visual trials	Years musical experience
<b>Visual d'</b>	.06	<b>.55 ***</b>	<b>-.48 **</b>	.08	.18	.04	.01	-.19	<b>.33 *</b>
<b>Visual criterion</b>		-.12	<b>.33 *</b>	.08	.05	.07	<b>.34 *</b>	-.18	.21
<b>Auditory d'</b>			<b>-.43 **</b>	.20	.07	.11	-.13	.14	.28
<b>Auditory criterion</b>				- .12	-.12	.02	.16	-.14	-.06
<b>WS</b>					-.14	.09	.07	-.02	-.07
<b>VVIQ</b>						<b>-.60 ***</b>	-.08	-.05	.14
<b>Auditory Imagery</b>							.16	.06	.21
<b>DESC</b>								-.09	.21
<b>% beeps for visual trials</b>									-.02

$p < .05 *$ ,  $p < .01 **$ ,  $p < .001 ***$

### 3.5 Discussion

The aim of the study was to investigate whether MS synaesthesia can be created in non-MS synaesthetes using either hypnosis or mental imagery, and how this differed to developmental MS synaesthesia. First the results suggest that participants are significantly more accurate at distinguishing between auditory in comparison to visual sequences, they were better at discriminating beep rhythms. This justifies the suitability of this task to investigate audition based improvements for visual sequence discrimination. Synaesthetes were significantly more accurate at visual sequence differentiation than low susceptible participants, replicating the findings of Saenz and Koch (2008). Not only was there a difference in accuracy, but MS synaesthetes showed a trend to respond “different” for visual trials whereas all other groups more often responded “same”. This is comparable to how participants responded in general towards the different stimuli, as there was an overall bias for participants to respond “different” for auditory trials, and “same” for visual. MS synaesthetes therefore responded to visual trials in the same manner as auditory trials.

Non-MS synaesthetes were found to often spontaneously use beeps in the baseline block for visual trials however they were not significantly more accurate than those who didn’t use beeps. This suggests that the “beeps” they heard didn’t enhance visual sequence differentiation in the same way as an MS synaesthesia concurrent. This was also in line with the results of our main research question, can post-hypnotic suggestion or mental imagery improve visual sequence differentiation? There was no improvement in the low or medium hypnotisable mental imagery groups, or the high hypnotisable post-hypnotic suggestion group’s accuracy or change in how participants responded between the baseline and experimental block. The suggestion to hear beeps for the visual sequences therefore didn’t improve accuracy. Regardless of whether the

non-MS synaesthetes spontaneously used beeps as a strategy to improve discrimination for visual trials, or whether they were told to in the experimental block, non-MS synaesthetes were not able to use them to significantly improve their accuracy.

After more exploratory correlational analysis relationships were found between years of musical experience/ tuition and visual trial accuracy for the experimental block. This could be because musicians learn to read musical notation, to know how a piece of music will sound even though they have only seen it. The link between visual and auditory percepts could be argued to be more closely related. Musicians have superior visuospatial performance on mental imagery or perceptual tasks (Brochard, Dufour, & Després, 2004) therefore this sequence differentiation task could tap into similar abilities. Further, musicians learn to recognise errors to improve their performance however musical experience was not correlated to auditory sequence performance, as may be expected. This could be due to the generally high performance on the auditory trials across groups.

The lack of behavioural advantage from the post-hypnotic suggestion is in line with previous research on GC synaesthesia which also found no improvement as a result of hypnotic suggestion (Anderson, Seth, Dienes, & Ward, 2014). If a behavioural advantage had been measured for the highly susceptible participants in either study, this would have been evidence against HOT theories of hypnosis, and perhaps support theories which propose special abilities can be induced using hypnosis (Brown & Oakley, 2004). Unlike the Anderson et al. (2014) study, the phenomenology of synaesthesia didn't require hypnosis to induce as many of the non-MS synaesthetes spontaneously used mentally created beeps as a task strategy. This makes intuitive sense, as although direction of sound can be determined, the sound is always experienced internally. Experiencing colours on graphemes required externalising a

hallucinatory percept, a task not conducted frequently. Mental imagery, in both cases however, was not akin to developmental synaesthesia in behaviour.

Variability in MS synaesthetes phenomenology is worth further investigation, on a larger scale. What is the range of concurrent sounds they experience, and how do they differ for different types of movement? Increasingly, the importance of phenomenology has come into light as although behavioural differences are informative for differences in processing in comparison to non synaesthetes to help establish its' cause, they are not a core aspect of the definition of synaesthesia (Deroy & Spence, 2013). Furthermore, MS synaesthete CT who was excluded from group analysis due to differences in his concurrent but was also high susceptible was able to experience an additional, phenomenologically different concurrent to his developmental concurrent after post-hypnotic suggestion. This suggests two very distinct mechanisms for the creation of the auditory concurrents, one for the developmental “crackling lightening” sounds and another for the suggested “beeps”. These seemed to happen in addition to the developmental sounds (accounted for an extra 10% of trials). This was only an individual participant, but does suggest a new avenue of research into comparing developmental and hypnotic synaesthesia mechanisms.

The response bias to answer “different” for visual trials by the MS synaesthetes could be explored further. Although they are more accurate at differentiating between trials than low hypnotisable participants, they were liberal with their “different” responses. Although the auditory concurrents aid in the differentiation, there may be a slight discrepancy between the sound sequences and visual sequences, in other words there may be error or noise in the translation of the visual signal into an auditory signal. This way, if going by the auditory sequence most of the time this will improve accuracy, but also produce an occasional extra false positive. The limits of translation

from visual to auditory sequence could therefore inform us why MS synaesthetes are able to use the auditory concurrent beneficially, whereas non-MS synaesthetes who try and use sound as a strategy to improve performance fail to improve.

This study didn't record phenomenology on a trial by trial basis which would have allowed more detailed exploration of the link between phenomenology and behaviour. By recording whether sounds were heard after each visual trial for both MS and non-MS synaesthetes, this would allow the general trend for high susceptible participants to perform better, and the apparent lack of improvement from concurrent sound in non-MS synaesthetes to be explored. Furthermore, only three MS participants were tested, which although similar to the sample in the original MS study (three MS synaesthetes) is limited

The current study found that post-hypnotic suggestion or mental imagery can't create behaviour similar to developmental MS synaesthetes, and that hearing sounds for flashing circles is a strategy spontaneously used by many non-MS synaesthetes. The lack of accuracy improvement for high susceptible participants supports theories that posit no new abilities can be created using hypnosis, such as the HOT theories. Non-MS synaesthetes who use the same strategy spontaneously don't demonstrate the same advantage, showing that MS synaesthesia is not created by purely functional mechanisms, such as mental imagery.

## **CHAPTER 4**

### **PRINCIPLE COMPONENT ANALYSES OF QUESTIONNAIRES MEASURING INDIVIDUAL DIFFERENCES IN SYNAESTHETIC PHENOMENOLOGY**

#### **-PAPER 3**

##### **4.1. Abstract**

Questionnaires have been developed for categorising grapheme-colour synaesthetes into two sub-types based on phenomenology: associators and projectors. The general approach has been to assume a priori the existence of two sub-types on a single dimension (with endpoints as projector and associator) rather than explore, in a data-driven fashion, other possible models. We collected responses from 175 grapheme-colour synaesthetes on two questionnaires; the Illustrated Synaesthetic Experience Questionnaire (Skelton et al., 2009) and the Projector-Associator Questionnaire (Rouw & Scholte, 2007). After Principle Component Analysis both questionnaires comprised two factors which coincide with the projector/ associator distinction. This suggests that projectors and associators are not opposites of each other, but separate dimensions of experience (e.g. some synaesthetes claim to be both, others claim to be neither). The revised questionnaires provide useful tools for researchers and insights into the phenomenology of synaesthesia.

#### 4.2. Introduction

For individuals with synaesthesia, an ‘inducer’ in one modality (percept or concept) triggers a ‘concurrent’ experience in another modality. One of the most common types of synaesthesia is grapheme-colour (GC) synaesthesia (Simner et al., 2006), where viewing a letter, number or even grammatical symbol can induce a consistent (Baron-Cohen et al., 1993) and automatic (Mattingley et al., 2001) colour experience. Although the experiences of individual synaesthetes are internally consistent, there are large differences between synaesthetes as to how they experience the colour. Each synaesthete has their own colour palette, i.e. the specific colours that they link with each grapheme. Although there are trends such as ‘A’ frequently being red (Simner et al., 2005) the actual colour that a synaesthete links to each grapheme, or the number of graphemes they have colour associations for, are not the only differences within this population.

GC synaesthetes have been roughly subdivided in previous research according to where they see their colour (Dixon et al., 2004). Projectors are classified as those who ‘see’ the colour in a projected location. This could be actually on the grapheme itself where it is located, for example if looking at a letter presented in black font on a piece of white paper, they would see the colour superimposed onto the grapheme on the actual paper or they may ‘see’ the colour floating in space between the grapheme itself and the person. The associator category encompasses those who ‘see’ the colours in their minds eye (irrespective of whether the colour is the same shape as the grapheme or a block of colour) and people who simply ‘know’ that a grapheme is a certain colour. Two questionnaires have been developed and used extensively within synaesthesia research to determine which end of a continuous dimension synaesthetes are, either a



projector or associator. These are the Illustrated Synaesthetic Experience Questionnaire (ISEQ; Skelton, Ludwig, & Mohr, 2009) and the Rouw and Scholte PA Questionnaire (RSPA; Rouw & Scholte, 2007).

Support for this sub classification of grapheme-colour synaesthesia has come from behavioural differences. Interference is found on a synaesthetic Stroop task when presented graphemes are in colours that are incongruent with their experience (relative to congruent) and this occurs for both projectors and associators. However, there are differences between projectors and associators depending on whether the task is to name the real colour (and ignore their synaesthesia) or name their synaesthetic colour (and ignore the real one) (Dixon et al., 2004). The authors predicted that projectors would demonstrate greater interference effects from photisms when having to name real colour, which they indeed observed. Projectors were faster at naming their photisms, whereas associators were faster at naming the real colour, which was also in line with their predictions. The results were presented as evidence for differences in the location of the concurrent photism interfering with the task. Other behavioural differences include a generally stronger correlation between similar graphemes (such as 'b' and 'd') and their concurrent colour which has been measured in projectors compared to associators (Brang et al., 2011).

Functional differences have also been measured between projector and associator synaesthetes with associators using areas more involved in memory processes, and projectors using more perceptual processing regions (Rouw & Scholte, 2010). Differences in V4 activation pathways has been measured in response to synaesthetic colour, fusiform gyrus for projectors and parietal lobe for associators (van Leeuwen, den Ouden, & Hagoort, 2011). Structural differences have also been measured with projector synaesthetes having greater inferior temporal cortex

connectivity than associator synaesthetes, the subtypes were measured via the projector-associator questionnaire (Rouw & Scholte, 2007). Therefore there is a range of evidence that differences, both behavioural and neurological, exist between the synaesthetic subtypes.

Although some differences have been measured between these sub groups, there are also instances where such a differentiation has not been observed. In one example, participants had to indicate the colour of a colour patch or black digit which was primed by the other (a colour primed a digit, or a digit primed a colour) (Gebuis, Nijboer, & Van der Smagt, 2009). Incongruent pairings caused increased reaction times and P3 latency and amplitude differences in the ERP signal however no differences were measured between projector and associator synaesthetes (note participants were only classified from direct questioning, not a specific questionnaire). Ward and colleagues found minimal differences between groups in an embedded figures test, where a shape (square, rectangle, diamond or triangle) has been hidden within an array of distractors (Ward et al., 2010). Here the shape and distractors are mirror image number 2s and 5s. As the components of these two numbers are identical, they are difficult to differentiate between. Colour improves accuracy in this task as it aids in detection of the shape through perceptual grouping of the graphemes, which is why grapheme-colour synaesthetes display superior performance (Ward et al., 2010). Although projector synaesthetes were more likely to report seeing a colour, there was no difference in behavioural performance,

Ward, Li, Salih and Sagiv (2007) have argued that that the projector-associator distinction, as it is typically articulated, fails to account for more nuanced phenomenological reports. The term “mind’s eye”, for instance, tends to be used very inconsistently to describe a range of experiences. Some GC synaesthetes claim to see

their colours inside their body (literally) and others claim to know the colour. Both would tend to be subsumed by the label ‘associator’. Similarly, some synaesthetes claim to experience colours externally but ‘in the air’ (at a fixed location from the body) and others experience it on the text itself (i.e. at a location defined by the inducer itself). Both of these experiences tend to be classed as ‘projector’ but there is some evidence that they can be dissociated behaviourally (Ward et al., 2007). Rather than a dichotomy, Ward et al. (2007) argued for a multiplicity related to different spatial frame of references (object-centred, body-centred, image-centred).

The present research has two purposes: one methodological, and one theoretical. In terms of methodology, we will explore the factor structure and statistical reliability (inter-correlations of items) of two published questionnaires using Principle Component Analysis (PCA). At present it is assumed, but not proven, that the responses to all questions related to being, say, an ‘associator’ are highly inter-correlated. It is also assumed, but not proven, that all questions load on to a single factor solution (with endpoints of projector and associator). For instance, on the RSPA a synaesthetes’ status as projector or associator is determined by subtracting the scores for associator questions from the projector questions. This tacitly assumes that all questions load on a single dimension rather than several dimensions. The analyses would also increase our theoretical understanding of synaesthetic phenomenology. For instance, some theories predict multiple sub-types of spatial phenomenology (Ward et al., 2007).

A more recent measure of synaesthetic experience is the Coloured Letters and Numbers (CLaN) questionnaire which is the only currently published synaesthesia questionnaire that has been analysed using Factor Analysis (more precisely, Maximum Likelihood Estimates) (Rothen, Tsakanikos, et al., 2013). This produced four distinct factors, localisation, automaticity/ attention, deliberate use, and longitudinal changes.

The localisation factor relates specifically to experiencing the colours localised on the grapheme ('projector') but, interestingly, questions that one might expect to relate to being an associator (e.g. knowing not seeing the colour, less intense colours) were not negatively loaded on to the same factor (instead they tended to be excluded from the factor structure). This does not support the view that an associator is, statistically or theoretically, the opposite of a projector. Nor did it offer strong support for the view that there would be at least three sub-types of grapheme-colour synaesthesia based on spatial phenomenology (Ward et al. 2007). The present study directly compares the CLaN against the more established ISEQ and RSPA questionnaires.

#### **4.3. Method**

Participants were recruited through email invitation of a synaesthetic participant database at the University of Sussex. Demographic questions and the two questionnaires (ISEQ and RSPA, in that order) were hosted on Bristol Online Survey, completion took approximately 20 minutes and no monetary reimbursement was given to participants. There were 175 participants who completed the survey, 156 female, age range 15-78 ( $M = 36.33$ ,  $SD = 16.22$ , age was not obtained for four participants). The study was granted clearance from the University of Sussex ethics committee.

Consistency was completed at a previous date (and recorded onto the database) by 67 participants using the Synaesthesia Battery (Eagleman et al., 2007) on which participants indicated the colour of their concurrent (if any) for the numbers 0-9 and alphabet. This is done three times, which allows the Synaesthesia Battery to calculate consistency of colour response for each grapheme. A score lower than one is considered to indicate a synaesthete (Eagleman et al., 2007) although this has been increased to 1.43 in a more recent analysis of online colour pickers (Rothen, Seth, Witzel, & Ward, 2013). Regardless of cut off, the lower the score, the more consistent the participant is

for their colour choice. Also on the database were responses for CLaN which is a questionnaire designed to measure multiple dimensions of GC synaesthesia phenomenology. It has been hosted the previous year on Bristol Online Survey. The 16 questions comprise four factors which are; localisation, deliberate use, automaticity and attention, longitudinal changes. This questionnaire uses a five point Likert-scale (1 = strongly disagree, 5 = strongly agree). As the database was used for recruiting participants, we were able to match these measures recorded previously to the RSPA and ISEQ questionnaires hosted on Bristol Online Survey.

The Rouw and Scholte (2007) PA Questionnaire has 12 questions: six are designed to measure the trait of associating, and six for projecting. Responses are measured using a five point Likert scale (1 = strongly disagree, 5 = strongly agree). The synaesthete type is calculated, again, by subtracting the mean associator score from the projector score, with negative values indicating associator and positive values a projector categorisation.

The Illustrated Synaesthetic Experience Questionnaire (Skelton et al., 2009) uses a seven point Likert scale (1 = least accurate, 7 = most accurate) to measure responses to five questions (3 associator, 2 projector). Each question has an accompanying image to demonstrate the particular grapheme and colour experience pairing in that question. To determine whether a synaesthete is a projector or associator, the mean associator score is subtracted from the mean projector score. The score must be greater than  $\pm 1$  for a categorisation, values around zero are classified as “undetermined”.

For our analyses, no initial grouping of questions are made because it is our aim to determine whether the categories of ‘projector’ and ‘associator’ emerge from a purely data-driven approach. It was decided to allow the data to guide the factor structure,

therefore the data would be analysed until all questions were included in a factor and each factor had internal validity and was reliable to the best the data would allow. This way we could explore the structure of the questionnaires to test whether colour locus is indeed one continuous dimension.

#### 4.4 Results

##### Consistency comparisons

Consistency measures were known for 67 participants ( $M = 0.78$ ,  $Range = 0.15-3.63$ ,  $MSE = 0.07$ ), therefore ANOVAs were conducted to confirm that responses for questionnaires were similar for those whom consistency measures were obtained for and not.

For the RSPA a two (consistency group; measured or not) by 12 (RSPA question number; 1 – 12) way ANOVA was conducted with between subjects for consistency and repeated measures for RSPA question number. The main effect of question was significant  $F(3.97, 686.56) = 55.75$ ,  $p < .001$  with Greenhouse-Geisser correction due to Sphericity violation. The main effect of consistency was not significant  $F(1, 173) = 0.27$ ,  $p = .60$ . Homogeneity of Variance was violated for four questions, however as this was only one third of questions, transformation would impair analysis of the questions and the p value was very large ( $p = .60$ ) therefore it was considered that the consistency measured ( $M = 2.99$ ,  $SE = 0.06$ ) and not measured ( $M = 2.94$ ,  $SE = 0.05$ ) groups were indeed similar. The interaction between consistency and RSPA question number was not significant  $F(3.97, 686.56) = 55.75$ ,  $p = .18$ . Therefore, retaining all participants for the Factor Analysis was deemed appropriate. In order to test whether the null hypothesis is supported, rather than there being insufficient evidence of a difference, is by conducting a Bayes factor analysis (Dienes, 2011). A value less than 1/3 supports the

null hypothesis, greater than 3 supports the alternative hypothesis, and between these values indicates insufficient evidence for either theory. A Bayes factor was calculated for each of the 12 questions, contrasting the group (consistency group; measured or not) using the values obtained from independent samples t-tests. The mean difference and SEM values are included in Appendix A. A two tailed normal distribution, with a SD of 2 was used as with a five point Likert scale, the maximum deviation from the central value is 2). Ten of the Bayes factors supported the null hypothesis, the other two (Q4 and Q9) indicated insufficient evidence for either hypothesis. This shows that the data from both groups was similar and can all be included in the factor analysis. The Bayes factor for each question can be seen in Appendix A.

For the ISEQ a two (consistency group; measured or not) by five (ISEQ question number; 1 – 5) way ANOVA was conducted with between subjects for consistency and repeated measures for ISEQ question number. There was a significant main effect of question  $F(3.44, 594.18) = 58.48, p < .001$  using Greenhouse-Geisser correction due to a violation of Sphericity. The main effect of consistency was not significant,  $F(1, 173) = 0.02, p = .88$  with the consistency measured ( $M = 3.71, SE = 0.14$ ) being similar to consistency not measured ( $M = 3.73, SE = 0.11$ ) participants. The interaction between consistency and ISEQ question was also not significant  $F(3.44, 594.18) = 0.79, p = .52$ . Therefore there were not differences between the groups of participants, and it was deemed appropriate to include all in the Factor Analysis. Bayes factors were calculated for the five questions contrasting the groups (consistency; measured or not) this time using 3 as the SD since the ISEQ uses a seven point Likert scale. All the Bayes factors supported the null hypothesis (see Appendix A) and therefore all data could be included in the factor analysis.

## **Rouw and Scholte PA Questionnaire (Rouw & Scholte, 2007)**

### **RSPA preliminary analysis**

Initially we tested the data to determine whether factor analysis was appropriate. The questions generally did not satisfy the assumption of normality. All items within the questionnaire should correlate with at least half the other questions, otherwise it suggests that it doesn't measure the same construct as the other questions. Q8 did not correlate significantly with half of the other questions and was therefore removed, after which all questions correlated significantly with at least half of the others. Q8 was "The colour is not on the paper but floats in space".

PCA was run using Direct Oblimin rotation as colour localisation may be a continuum and therefore related aspects of a bimodal distribution. Eigenvalues over 1 were used for inclusion as a component, and absolute values under .4 were suppressed. After the initial analysis, two factors were retained and all criteria other than Kaisers criterion (1974) were met. The analysis was therefore repeated using a forced two factor solution supported by the scree plot. After the second analysis, reliability would have been improved by removing Q9, therefore PCA was repeated without this question based on extraction of factors with eigenvalues greater than 1. Q9 was "The colour has the same shape as the letter number".

### **RSPA initial factor analyses**

Principle Component Analysis was run using Direct Oblimin rotation as colour localisation may be a continuum and therefore related. Eigenvalues over 1 were used for inclusion as a component, and absolute values under .4 were suppressed.



The Determinant was well above the required value of .00001 (.003), the Keiser-Meyer-Olkin (KMO) measure of sampling adequacy was very good at .87 (Kaiser, 1974) and Bartlett's Test of Sphericity was highly significant ( $X(55) = 960.90, p < .001$ ) therefore factor analysis was deemed appropriate for the data. Average communalities after extraction were adequate at .71. Three components with Eigenvalues over 1 were extracted initially, explaining a total of 70.71 % of the variance however Kaiser's Criterion were not met therefore the Scree Plot (see Appendix B) was checked which suggested a two factor solution. The Factor Analysis was therefore repeated with a fixed two factor solution.

Average communalities after extraction was now reduced to .58 which is near adequate. The total variance explained was 58.17 %, with Factor 1 accounting for 45.01 % and Factor 2 an additional 13.15 %. Q7 no longer loaded onto a factor, therefore it was removed and the analysis repeated. All questions still correlated significantly with at least half the others, the Determinant (.006), KMO (.89) and Bartlett's ( $X(45) = 866.93, p < .001$ ) all deemed Factor Analysis suitable. Average communalities after extraction were .62. A total of 62.31 % of the variance was explained, Factor 1 accounted for 47.85 % and Factor 2 a further 14.46 %. Rotation converged after 10 iterations and all questions now loaded onto a factor. Reliability analysis showed that Cronbach's Alpha increased for Factor 1 only when question 5 was removed, resulting in a value of .90. Although this would improve reliability, Cronbach's Alpha was already very high and therefore removal of this question was not deemed necessary. For Factor 2 Cronbach's Alpha would increase if question 9 was removed, with it improving to .68. It was therefore decided to remove question 9 and repeat the analysis. Q9 was "The colour has the same shape as the letter number".

### **RSPA final factor analysis and statistical reliability**

All correlations were now significant, the Determinant was good (.008) as was the KMO (.89; Kaiser, 1974) and Bartlett's Test of Sphericity was highly significant ( $X(36) = 829.02, p < .001$ ). Factor analysis therefore appeared appropriate for the data. No fixed number of factors were forced so that the data guided the structure and Direct Oblimin rotation was again used.

Rotation converged after 10 iterations. Average communalities after extraction was .66 which was close to adequate. Two factors with eigenvalues over 1 were extracted. Factor 1 (Colour externalisation) accounted for 52.92 % of the variance, and Factor 2 (Internal colour) a further 13.37 % of variance, totalling 66.29 % of variance. Although Kaisers Criterion were not met, the Scree plot confirmed a 2 factor solution. As two factors were obtained this suggests that colour locus is not one continuous dimension as this structure was guided by the data.

“Associator” had good very good internal reliability, as was evident in a Cronbach's alpha value of .84. Removal of Q1 would have marginally increased  $\alpha$  (by .006) however this minor increase of was considered not so this question was retained. “Projector” also had very good internal reliability  $\alpha = .83$ . Removing Q5 would increase  $\alpha$  to .90 but again, as reliability was already high this was retained. This can be seen in Table 4.1.

**Table 4.1.**

Factor loadings and reliability analysis.

Scale and Items	Reliability	Eigenvalue	<i>M</i>	<i>SD</i>	1	2
<b>1. Projector</b>	$\alpha = .84$	4.76	2.79	1.64	.71	
<b>Q1.</b> When I look at a certain letter or number, I "see" a particular colour.						
<b>Q4.</b> It seems that the colour is on the paper where the letter/number is printed.			1.96	1.36	.61	
<b>Q6.</b> The colour is, if it were, projected onto the letter/number.			2.44	1.55	.84	
<b>Q11.</b> I see the synaesthetic colour very clearly in proximity of the stimulus (e.g. on top of it or behind it or above it).			2.07	1.43	.77	
<b>Q12.</b> When I look at a certain letter/number, the synaesthetic colour appears somewhere outside my head (such as on the paper).			1.98	1.44	.66	
<b>2. Associator</b>	$\alpha = .83$	1.20	3.93	1.46		.85
<b>Q2.</b> When I look at a certain letter/ number, the accompanying colour appears only in my thoughts and <b>not</b> somewhere outside my head (such as on the paper).						
<b>Q3.</b> When I look at a certain letter/number, the accompanying synaesthetic colour comes in my thoughts but on the paper appears only the colour in which the letter/number is printed (e.g. a black letter against a white background?).			4.06	1.38		.81
<b>Q5.</b> The figure itself has no colour but I am aware that it is associated with a specific colour.			3.53	1.49		.70
<b>Q10.</b> I see the colour of a letter/number only in my head.			3.80	1.48		.78

## **Illustrated Synaesthetic Experience Questionnaire (Skelton et al., 2009)**

### **ISEQ preliminary analysis**

The appropriateness of completing factor analysis on the data was first determined. None of the questions followed a normal distribution, with substantial positive and negative skews being evident. Questions 3 and 5 only significantly correlated with one other question which would generally suggest they do not measure the same construct, however due to the very small number of questions they were retained, as removing them would reduce the total items to 3 which prevents any more than one factor being created stopping exploratory analysis of the questionnaires. Therefore these questions were retained.

### **RSPA initial factor analysis**

Initially, Principle Component Analysis was run using Direct Oblimin rotation as localisation of colour may be part of a continuum and therefore these would be considered related factors. Eigenvalues over 1 were retained, and absolute values under .40 were suppressed. The Determinant was .664, well above the required value of .00001 and Bartlett's Test of Sampling Adequacy was highly significant ( $X(10) = 70.204, p < .001$ ) however the KMO measure of sampling adequacy was only .439 which is below the recommended value of .5 (Kaiser, 1974). . Average communalities after extraction was only .57. Initially, two components were extracted explaining a total of 56.83 % of the variance. After rotation, which converged after 7 rotations, Q3 did not load onto either factor and was therefore removed. As Kaiser's Criterion were not met the scree plot (see Appendix B) was referred to and it supported a two factor solution. The factor analysis was therefore repeated using a forced two factor solution with questions 1, 2, 4 and 5. Q3, 'You experience a coloured copy of the letters in the

'mind's eye' and black and white on the page' was one of the associator questions. This left two questions classified as projector and two as associator from the original questionnaire.

### **ISEQ final factor analysis and statistical reliability**

Q5 still didn't correlate significantly with half the other questions. The Determinant was .693, Bartlett's was highly significant ( $X(6) = 62.98, p < .001$ ) and KMO was inadequate at .44 (Kaiser, 1974). Average communalities after extraction was now .69 which is near .7 and therefore acceptable however Kaiser's Criterion were still not met. The scree plot still suggested a two factor solution. The total variance explained was high at 69.33 %. Factor 1 (Projector) explained 35.43 % of the variance, and Factor 2 (Associator) a further 33.91 %. Therefore, the Factor Analysis showed that a single factor solution was not optimal, and colour locus includes more than one dimension (two using this questionnaire). As there were only two questions in each factor, Cronbach's Alpha could not be calculated. Spearmans's Rho Correlation was therefore used. The correlation for both the Projector and Associator factors were highly significant as can be seen in Table 4.2.

**Table 4.2.**

Factor loadings and reliability analysis.

Scale and Items	Reliability	Eigenvalue	<i>M</i>	<i>SD</i>	1	2	<i>P</i>
<b>1. Projector</b>	$T_s = .47$	1.42	2.56	1.88	.85		< .001
<b>Q2.</b> You "see" a specific colour > The colour has the same shape as the letter or number > The colour is not on the page, but floating in space							
<b>Q1.</b> You "see" a specific colour > The colour has the same shape as the letter or number > The colour looks like it is on the page			3.08	2.23	.82		
<b>2. Associator</b>	$T_s = .33$	1.36	2.86	2.19		.84	< .001
<b>Q4.</b> You experience a block of colour in your 'minds eye' and black and white on the page							
<b>Q5.</b> You experience a sensation of knowing a letters colour			5.02	2.18		.77	

**Comparison of original and revised questionnaires**

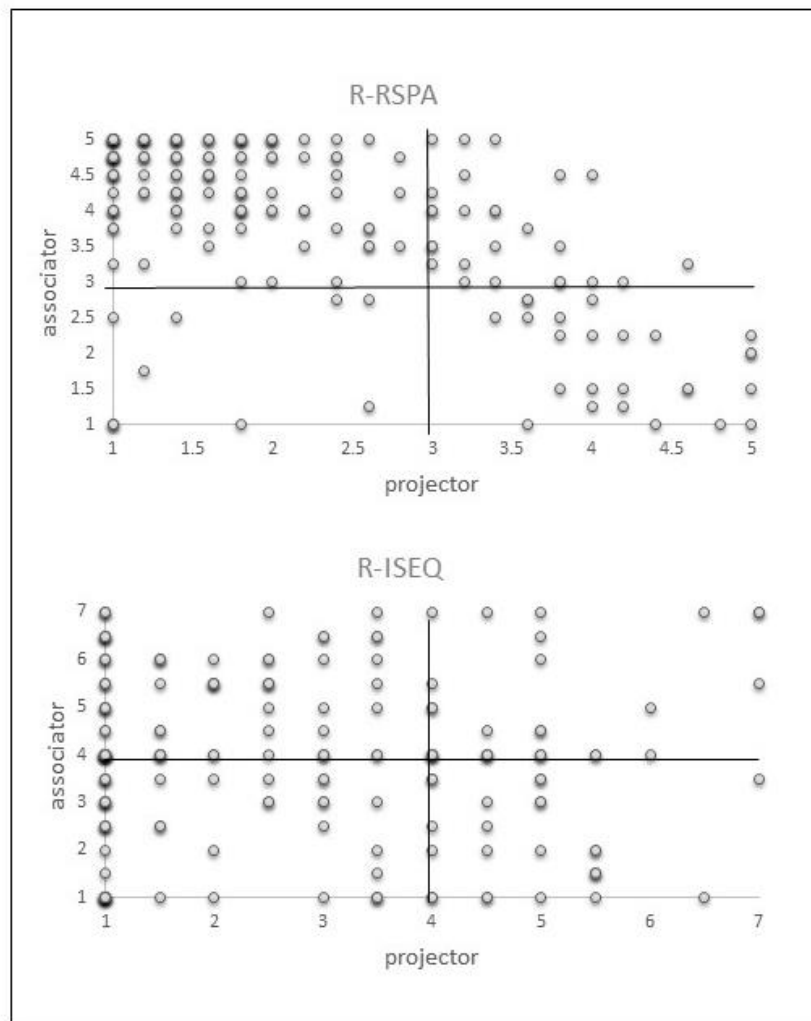
First the changes after modification of the questionnaires was investigated. For both questionnaires before and after modification, the mean score was calculated for each factor separately to prevent bias from uneven question numbers. Wilcoxon Signed-Rank Test showed the ISEQ was significantly different from the R- ISEQ ( $p < .001$ ) with the mean of the original ISEQ ( $M = -1.506$ ,  $SD = 2.246$ ) being lower than the R- ISEQ ( $M = -1.120$ ,  $SD = 2.514$ ). This shows that the ISEQ defined people more as associator than the R-ISEQ. Wilcoxon Signed-Rank Test also showed that the RSPA was significantly different from the R-RSPA ( $p < .001$ ) with the mean of the original RSPA ( $M = -0.986$ ,  $SD = 1.748$ ) being greater than the R-RSPA ( $M = -1.578$ ,  $SD = 2.093$ ). This time the original questionnaire scored participants as less strongly associator than the revised questionnaire.

In order to determine how the modifications changed the distribution of scores, the number of participants classified as one type or another was determined. The original questionnaire classification systems were used. For both the score is calculated by subtracting the mean associator value from the mean projector value. For the RSPA, if the value is negative the participant is an associator, positive and they are a projector. For the ISEQ,  $>1$  indicates projector,  $< -1$  associator, and between  $\pm 1$  they are undetermined. This is shown in Table 4.3.

**Table 4.3.**Classifications of the synaesthetes.

Questionnaire	ISEQ	RSPA	R-ISEQ	R-RSPA
Projector	25	41	33	26
Associator	148	134	137	149
Undetermined	2	N/A	5	N/A

As can be seen from Table 4.3 there is not a consensus between the questionnaires on how many people are associators or projectors. The correlation between the projector and associator dimensions of the R-ISEQ and R-RSPA are however highly correlated, see Figure 4.1.

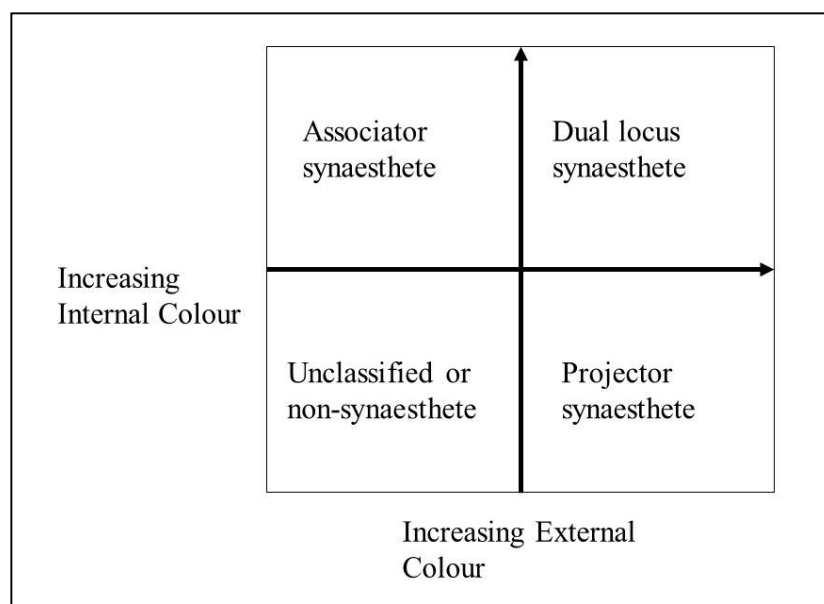


**Figure 4.1.** Mean projector and associator scores for the revised questionnaires (R-ISEQ and R-RSPA).

As can be seen from Figure 4.1, both questionnaires have difficulty distinguishing between associator and projector synaesthetes. If localisation is a continuous dimension with a bimodal distribution then it would be expected that participants experienced one type of localisation only. Furthermore this is necessary for the coding scheme used to calculate the sub type for each participant, as the mean associator score is subtracted from the mean projector score (Rouw & Scholte, 2010;



Skelton et al., 2009). This calculation is based on the theory that it is one bimodally distributed dimension and that participants should not score highly on both. As can be seen from Table 4.3 this is clearly not the case, and modification through factor analysis has not resolved this problem. Furthermore, for the RSPA it seems insufficient to consider synaesthetes undetermined if they do not clearly fit an associator or projector classification. Combined with the two factor solutions for the revised versions of both questionnaires this does suggest that there are two separate dimensions of colour locus, internal and external colour. For the R-RSPA, 7.43% responded highly to both projector and associator dimensions, and for the R-ISEQ 6.86%.



**Figure 4.2.** Diagram of colour locus for graphemes.

Figure 4.2 shows the suggested new classification system for grapheme-colour synaesthesia sub types which takes into consideration the two separate colour locus dimensions. Now, a synaesthesia sub type can be one of three categories; projector, associator or dual locus. This allows non-synaesthetes to be isolated from dual locus synaesthetes as they would both previously obtain an “undetermined” classification on

the RSPA. If a participant scores highly on both the associator and projector dimensions, when the mean associator value is subtracted from the associator value a score around zero is likely. This way, they would have a similar score to a non-synaesthete who scores low on both dimensions. Using the above diagram we can differentiate between these two groups.

### Comparison against the CLaN Questionnaire (Rothen, Tsakanikos, et al., 2013)

**Table 4.4.**

Spearman's Rho correlations between the projector and associator dimensions of the R-ISEQ and R-RSPA, the four dimensions of the CLaN questionnaire and the Synaesthesia Battery (Eagleman et al., 2007) consistency measure.

	R-ISEQ Associator	R-RSPA Projector	R-RSPA Associator	Localisation	Deliberate Use	Automatic ity/ Attention	Longitudinal Changes	Consistency
<b>R-ISEQ Projector</b>	-.04	<b>.67 ***</b>	<b>-.39 ***</b>	<b>.54 ***</b>	<b>.15 *</b>	<b>.24 **</b>	.01	.06
<b>R-ISEQ Associator</b>		-.05	<b>.28 ***</b>	-.01	-.08	.04	<b>-.21 **</b>	-.00
<b>R-RSPA Projector</b>			<b>-.51 ***</b>	<b>.67 ***</b>	<b>.20 **</b>	<b>.33 ***</b>	-.00	.05
<b>R-RSPA Associator</b>				<b>-.45 ***</b>	-.03	<b>-.15 *</b>	-.01	-.02
<b>Localisation</b>					<b>.35 ***</b>	<b>.38 ***</b>	.04	.02
<b>Deliberate Use</b>						<b>.17 *</b>	.08	-.10
<b>Automatic ity/ Attention</b>							<b>.21 **</b>	-.04
<b>Longitudinal Changes</b>								-.06

Note:  $p < .05$  \*  $p < .01$  \*\*  $p < .001$  \*\*\*

As can be seen from Table 4.4, the strongest relationships between the revised questionnaires and other measurements is the Localisation dimension of the CLaN

questionnaire which had significant correlations with the projector dimension of the R-ISEQ and both dimensions of the R-RSPA, providing criterion validation for the revised questionnaires. The associator dimension of the R-ISEQ only correlated significantly with the longitudinal changes of the CLaN questionnaire. Interestingly, none of the components correlated significantly with the Synaesthesia Battery consistency measurement (Eagleman et al., 2007).

As the CLaN had a question which corresponds to the dual locus category we are proposing (Q6 “I experience the synaesthetic colours in several locations at the same time (for instance, both on the screen and literally inside my head or some other combination)”), we compared answers to this question by participants who were categorised as dual locus synaesthete or not. An independent samples Mann-Whitney U test comparing participants categorised as dual locus ( $N = 13$ ) using the R-RSPA against those who were not dual locus ( $N = 162$ ), on CLaN Q6 response, demonstrated a significant difference ( $p = .01$ ). Dual locus participants agreed to a greater extent with Q6 ( $M = 3.31$ ,  $MSE = 0.36$ ) than non dual locus ( $M = 2.29$ ,  $MSE = 0.11$ ). The same analysis for R-ISEQ found the difference between dual locus ( $N = 12$ ,  $M = 2.75$ ,  $MSE = 0.37$ ) and not dual locus ( $N = 163$ ,  $M = 2.34$ ,  $MSE = 0.11$ ) to be non significant ( $p = .22$ ). Therefore, participants appeared to agree with a dual locus classification when assigned this compared to non dual locus synaesthetes, though only to a significantly greater degree when measured using the R-RSPA.

#### 4.5. Discussion

We conducted PCA on two questionnaires (RSPA and ISEQ) designed to measure colour locus for GC synaesthetes to determine whether colour locus was indeed a continuous dimension. After analysis, both questionnaires had been revised and contained two factors corresponding roughly to associator and projector factors with

good internal reliability and criterion validity as measured using the CLaN. We have therefore successfully analysed the RSPA and ISEQ, and produced new versions, the R-RSPA and R-ISEQ.

The RSPA originally covered the construct of synaesthetic colour experience more thoroughly than the ISEQ. The distribution of all the questions violated the assumption of normality. This is not surprising considering that a lot of the questions, although using a Likert scale, are measuring responses which are almost bimodal. If asked, “It seems that the colour is on the paper where the letter/number is printed” most people are going to respond in a yes/ no manner simply because of the way the question is phrased and the nature of the question. The same can be argued for the majority of questions. This causes problems not just for PCA, but for any statistical analysis which requires normally distributed data. The bimodal response distribution may however aid distinguishing between GC synaesthesia sub types. This issue shall remain in synaesthesia questionnaires until a more appropriate questionnaire response method is developed, however this is an issue for future consideration.

Although one question was removed, the general structure of the ISEQ questionnaire remained the same in terms of the question split between projectors and associators. This is unsurprising since there were only five questions in the initial questionnaire and with only two questions in each factor, reliability could only be measured through correlation. The existence of two distinct factors however goes against the continuous dimension classification of the ISEQ.

It should also be noted, that although the inclusion of such a few questions is beneficial for keeping the questionnaire brief to complete, this makes it difficult to analyse internally as a standalone questionnaire. As at least two questions have to be

grouped in order for a factor to exist, starting with five questions is very restrictive. This meant that although there were issues with non-normal distributions no questions could be removed in the preliminary analysis. The very small question size also means that the full range of synaesthetic experience may not be extensively measured. As this questionnaire has been used widely in the synaesthesia literature, it was however considered important to investigate the dimension(s) underlying the projector/associator distinction.

The final R-RSPA had a two factor solution which did not support the continuous dimension of the original questionnaire. The two factor solution however is consistent with the factor structure we obtained from the R-ISEQ, and therefore we conclude that grapheme-colour synaesthesia subtype is not one continuous dimension, but two distinct dimensions. It should be noted that although two factors were found going against a continuous dimension, the questions were still grouped in the same way as the original questionnaires. It is interesting that the CLaN did not find distinct projector and associator factors. This could be due to either the restricted number of associator questions they included, or may demonstrate that the variability within GC synaesthetes is better accounted for by a more multi-dimensional questionnaire. One question from the CLaN which supports our dual locus sub type is the questions “I experience the synaesthetic colours in several locations at the same time (for instance, both on the screen and literally inside my head or some other combination)” which remained in the CLaN after Factor Analysis and was significantly correlated to the projector factor of the R-ISEQ and both factors in the R-RSPA. Therefore, the dual locus phenomenology experienced by some synaesthetes in our study is validated by the CLaN, but was not allowed for in the original versions as the process of subtracting associator from projector scores would have given the misleading impression of

experiencing colours ‘nowhere’ instead of ‘everywhere’. The fourth category (in the lower left quadrant) effectively denies being a projector or an associator. One possibility is that some of these participants are not, in fact, synaesthetes at all. A more interesting possibility is that they would agree with other kinds of statements about spatial phenomenology (e.g. experiencing them literally inside the body, or externally but not on the page). These questions were not included at all on the RSPA or ISEQ. They were included in the CLaN but may have been insufficient in number (either number of participants, or number of items, or both) to emerge as a separate factor.

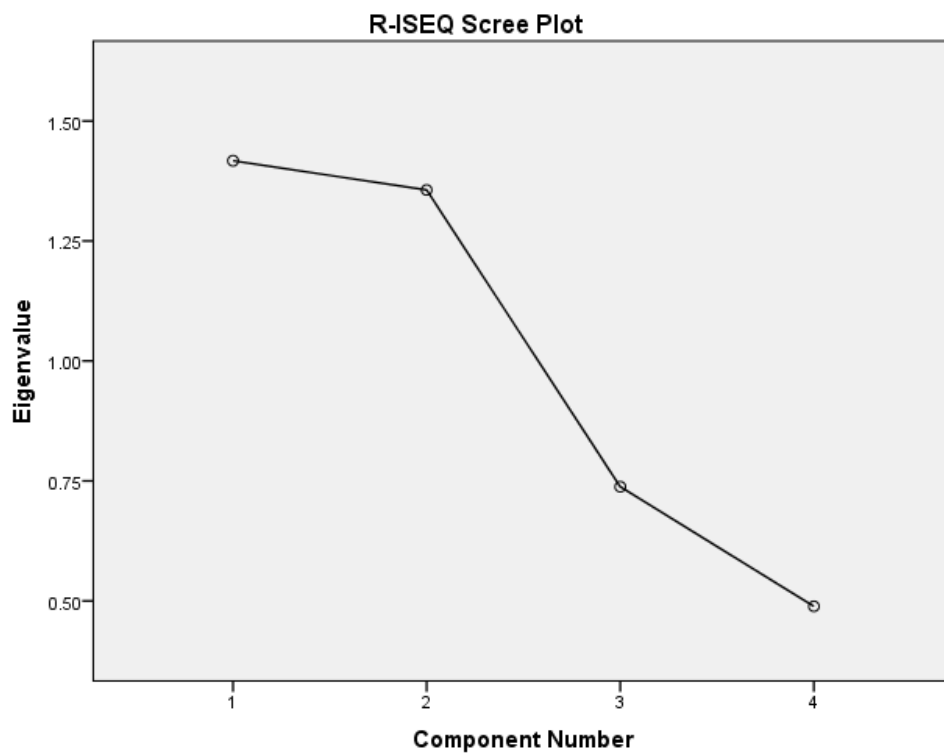
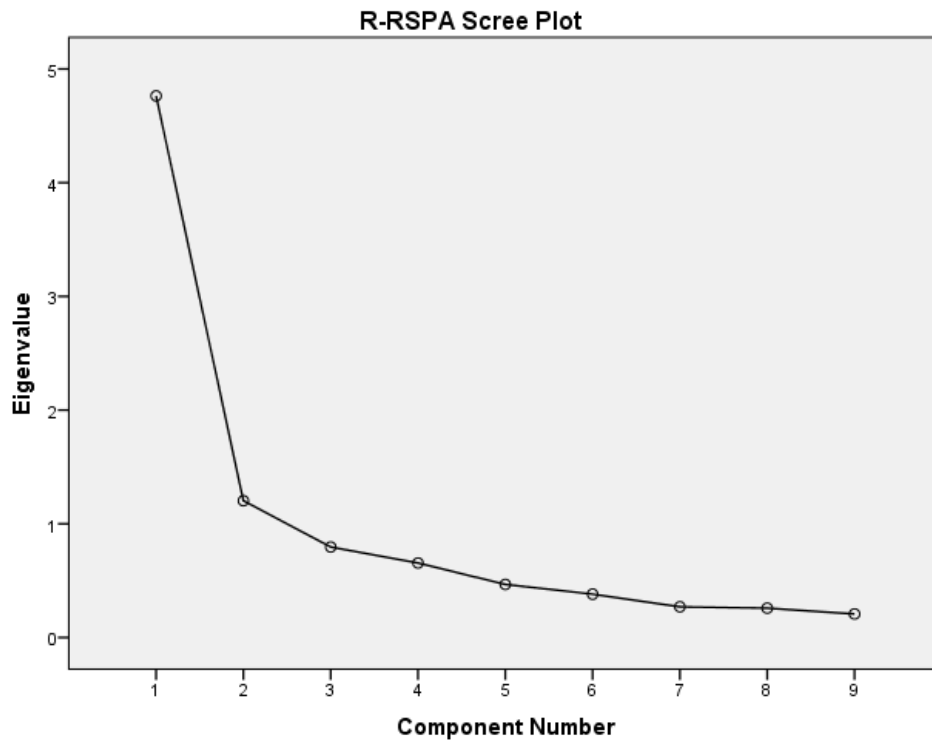
The Synaesthesia Battery consistency measure was not found to correlate significantly with the projector or associator dimensions. This is interesting considering that consistency is one of the main criteria used for defining someone as a synaesthete (Auvray & Farina, in press). This suggests that consistency of colour is not the most important aspect of phenomenology as an inclusion requirement for synaesthesia research, it is the experience of colour itself.

We propose that there is not one continuous subtype of grapheme-colour synaesthesia, rather there are two separate dimensions. Synaesthetes could therefore be categorised (minimally) as a projector, associator or dual locus synaesthete. Using this categorisation may improve analysis of differences between groups, as the previously standard system of subtracting association scores from projector scores means that synaesthetes who agree to both dimensions could be wrongly categorised, and perhaps generate noise within a projector/ associator participant group. We believe that the R-ISEQ and R-RSPA provide more valid measures of the subtypes, and should be used alongside the CLaN for more precise synaesthesia investigation.

#### 4.6. Appendix

##### Appendix A

Question	SEM	Mean Diff	Bayes factor	Conclusion
RSPA 1	0.25	-0.29	0.24	Supports Null
RSPA 2	0.23	0.07	0.12	Supports Null
RSPA 3	0.22	0.02	0.11	Supports Null
RSPA 4	0.22	-0.40	0.56	Insufficient evidence
RSPA 5	0.23	0.32	0.30	Supports Null
RSPA 6	0.24	-0.01	0.12	Supports Null
RSPA 7	0.24	0.29	0.24	Supports Null
RSPA 8	0.20	0.22	0.18	Supports Null
RSPA 9	0.25	-0.54	1.23	Insufficient evidence
RSPA 10	0.24	0.18	0.16	Supports Null
RSPA 11	0.23	-0.24	0.20	Supports Null
RSPA 12	0.22	-0.13	0.13	Supports Null
ISEQ 1	0.35	-0.45	0.26	Supports Null
ISEQ 2	0.29	0.13	0.11	Supports Null
ISEQ 3	0.35	0.28	0.16	Supports Null
ISEQ 4	0.34	0.16	0.13	Supports Null
ISEQ 5	0.34	0.13	0.12	Supports Null

**Appendix B**



## Appendix C

### R-RSPA Questionnaire

Q1. When I look at a certain letter or number, I "see" a particular colour.

Q2. When I look at a certain letter/ number, the accompanying colour appears only in my thoughts and not somewhere outside my head (such as on the paper).

Q3. When I look at a certain letter/number, the accompanying synaesthetic colour comes in my thoughts but on the paper appears only the colour in which the letter/number is printed (e.g. a black letter against a white background?).

Q4. It seems that the colour is on the paper where the letter/number is printed.

Q5. The figure itself has no colour but I am aware that it is associated with a specific colour.

Q6. The colour is, if it were, projected onto the letter/number.

Q7 (originally Q10). I see the colour of a letter/number only in my head.

Q8 (originally Q11). I see the synaesthetic colour very clearly in proximity of the stimulus (e.g. on top of it or behind it or above it).

Q9 (originally Q12). When I look at a certain letter/number, the synaesthetic colour appears somewhere outside my head (such as on the paper).

Projector questions; 1, 4, 6, 8 and 9

Associator questions; 2, 3, 5, 7

\* Note that question numbers have been changed from the original Rouw and Scholte Projector Associator questionnaire

### R-ISEQ Questions

Q1. You "see" a specific colour > The colour has the same shape as the letter or number > The colour looks like it is on the page

Q2. You "see" a specific colour > The colour has the same shape as the letter or number > The colour is not on the page, but floating in space

Q3 (originally Q4). You experience a block of colour in your 'minds eye' and black and white on the page

Q4 (originally Q5). You experience a sensation of knowing a letters colour

---

Projector questions; 1 and 2

Associator questions; 3 and 4

\* Note that question numbers have been changed from the original Illustrated Synaesthetic Experience Questionnaire, and the corresponding images are also required from the original questionnaire

## **Appendix D**

### **Coloured Letters and Numbers (CLaN) Questionnaire** (Rothen, Tsakanikos, et al., 2013)

---

1. I experience the synaesthetic colours even if I do not attend to them specifically (e.g., while reading a book)
2. I see the synaesthetic colours on the computer screen (or very close to it)
3. It feels like I have to go and fetch the colours, rather than the colours coming to me
4. I experience the synaesthetic colours in several locations at the same time (for instance, both on the screen and literally inside my head or some other combination)
5. I only experience the synaesthetic colours of letters/numbers if I think about them as having a colour
6. When I am looking quickly at a page of a book the synaesthetic colours appear before I am aware of what the letters/words are
7. I do not “see” colours when I look at the letters/numbers
8. It seems that the colour is on the screen where the letter/number is printed
9. The synaesthetic colours appear automatically without any effort on my part
10. I can point to the location of the synaesthetic colours
11. My synaesthetic colours did not change their intensity over the years
12. I use my synaesthetic colours deliberately for remembering sequences of numbers (e.g., PINs, telephone numbers)
13. I deliberately try to use my synaesthetic colours in my everyday life
14. I use my synaesthetic colours to remember dates and plan appointments (e.g., 28.02.2010)

15. My synaesthetic colours were weaker in the past (i.e., years ago)

16. My synaesthetic colours were stronger in the past (i.e., years ago)

---

**Rouw and Scholte Projector Associator (RSPA) Questionnaire (Original) (Rouw & Scholte, 2007)**

---

1. When I look at a certain letter or number, I "see" a particular colour.
  2. When I look at a certain letter/ number, the accompanying colour appears only in my thoughts and "not" somewhere outside my head (such as on the paper).
  3. When I look at a certain letter/number, the accompanying synaesthetic colour comes in my thoughts but on the paper appears only the colour in which the letter/number
  4. It seems that the colour is on the paper where the letter/number is printed.
  5. The figure itself has no colour but I am aware that it is associated with a specific colour.
  6. The colour is, if it were, projected onto the letter/number.
  7. I do not see the letters/numbers literally in a colour but have a strong feeling that I know what colour belongs to a certain letter/number.
  8. The colour is not on the paper but floats in space.
  9. The colour has the same shape as the letter/number.
  10. I see the colour of a letter/number only in my head.
  11. I see the synaesthetic colour very clearly in proximity of the stimulus (e.g. on top of it or behind it or above it).
  12. When I look at a certain letter/number, the synaesthetic colour appears somewhere outside my head (such as on the paper).
- 

**Illustrated Synaesthetic Experience Questionnaire (ISEQ; Original) (Skelton et al., 2009)**

---

1. > You "see" a specific colour > The colour has the same shape as the letter or number > The colour looks like it is on the page
2. > You "see" a specific colour > The colour has the same shape as the letter or number > The colour is not on the page, but floating in space

3. > You experience a coloured copy of the letters in the 'minds eye' and black and white on the page
  4. > You experience a block of colour in your 'minds eye' and black and white on the page
  5. > You experience a sensation of knowing a letters colour
-

## CHAPTER 5

### GRAPHEME-COLOUR SYNAESTHESIA REQUIRES CONSCIOUS AWARENESS FOR PERCEPT BINDING

#### -PAPER 4

##### 5.1 Abstract

Grapheme-colour synaesthesia is when letters, numbers or symbols concurrently evoke a colour. This study investigates the extent to which a grapheme must be consciously perceived for colour concurrents to be elicited and the extent to which subliminally presented coloured graphemes break through into awareness. This is explored using techniques that enable stimuli to be presented for long durations whilst remaining preconscious: gaze-contingent crowding (GCC) and continuous flash suppression (CFS). In Experiment 1, GCC was used to determine whether subliminally presented digits viewed by synaesthetes would A) influence digit responses B) influence colour responses C) evoke colour concurrents. Preconsciously presented digits influenced behavioural responses to digits, but not to colours, suggesting the digit, but not synaesthetic colour, is activated. Some synaesthetes (those that project colours externally) did report colour experiences to ‘unseen’ digits but the colours did not typically correspond. In the other three experiments, CFS was used to investigate whether time for stimuli to break through to conscious awareness was influenced by 1) colourfulness of the grapheme’s synaesthetic concurrent (greyscale or coloured) 2) congruency of the grapheme’s font colour and concurrent colour (synaesthetic Stroop) 3) congruency of colour word and font colour (a standard Stroop). Conscious detection of graphemes was not influenced by grapheme colourfulness or grapheme-colour congruency. However a traditional Stroop effect for colour words was observed. This

suggests that despite the fact that graphemic stimuli are semantically processed unconsciously, this is insufficient to elicit the typical synaesthetic colour. Even when graphemes are viewed for long durations, grapheme-colour synaesthesia therefore requires conscious perception for the grapheme and colour to bind.

## 5.2 Introduction

Synaesthesia is a fascinating condition in which a particular perception (inducer) triggers a perceptual or conceptual experience (concurrent) in another (or the same) modality. One of the most common forms is grapheme-colour (GC) synaesthesia, where the individual experiences colours when viewing letters, numbers or grammatical symbols, which occurs in approximately 1% of the population (Simner et al., 2006). The consistency of the colour induced by a particular grapheme (Baron-Cohen et al., 1993) allows studies to be conducted which manipulate the pairings of grapheme and colour such that they are either correct for the individual synaesthete (congruent) or subjectively mismatching (incongruent). Using these congruent and incongruent pairings, a variety of cognitive processes affected by GC synaesthesia can be investigated. We used this premise to test whether a grapheme triggers and binds with its concurrent colour even when the grapheme is not consciously seen.

The generation of synaesthetic colours is automatic, as demonstrated through the regularly used synaesthetic Stroop task (Dixon, Smilek, & Merikle, 2004; Mattingley, Rich, Yelland, & Bradshaw, 2001; Mattingley, Payne, & Rich, 2006; Nikolić, Lichti, & Singer, 2007). In this task, a GC synaesthete has to name either the font colour, or the concurrent photism colour which they experience, for individual graphemes. Synaesthetes have longer reaction times (RTs) and make more errors when the font colour and photism colour do not match, presumably due to interference from the mismatching photism, as in the standard Stroop effect (Stroop, 1935). The synaesthetic

Stroop task has also been modified to investigate the different levels of interference caused by variations of incongruent colour and grapheme pairings. When the font colour is an opponent colour to the grapheme's concurrent the greatest interference is created, in comparison to colours on the other colour channel (Nikolić et al., 2007). Presenting a grapheme which produces a red concurrent in green font will therefore cause greater interference than presenting it in blue or yellow. The Stroop task is therefore a highly useful and modifiable tool in synaesthesia research.

To investigate whether graphemes trigger the concurrent colour when the grapheme is not consciously perceived, Mattingley, Rich, Yelland and Bradshaw (2001) presented graphemes that were followed by a colour patch presented in a colour either congruent or incongruent in relation to the concurrent for the grapheme. Masking was used to suppress conscious detection of the grapheme. When the grapheme was presented for 500ms (the longest presentation time) Stroop interference effects were evident. It was confirmed in a detection task that these graphemes were consciously perceived. When the grapheme was only presented for 28 or 56ms (and confirmed not to be consciously detected) the Stroop interference effects were no longer present. This was given as evidence that a grapheme doesn't elicit its concurrent colour when it is viewed unconsciously. The graphemes were, however, displayed for such a brief time that priming the concurrent colour with the strength needed to influence colour identification (Blake, Palmeri, Marois, & Chai-Youn, 2005) or even a processing degree sufficient to prime the concurrent colour at all may not have been possible.

An alternative approach is to present a grapheme without masking, but reduce awareness of the grapheme by manipulating attentional demands. Mattingley, Payne and Rich (2006) took this approach in a dual task paradigm again using a synaesthetic Stroop manipulation. Synaesthetic participants had to name a target colour patch that

was presented after a grey inducer digit, the pairings being either congruent or incongruent. This time, however, there was a secondary task as the grey digit was presented within a diamond outline with sides intersected by uneven gaps. Participants had to detect where the larger gap was on the diamond. When the odd gap was much larger than the gap on the opposite side of the diamond, this was a low attention load task, when it was only slightly larger it was more difficult to distinguish and therefore a high attention load task. During the high load condition, the Stroop interference was lower than during the low load condition, demonstrating that attentional load modulated the Stroop task interference. Since the Stroop interference effect was still evident in the low load condition and, indeed, awareness of the grapheme was not directly assessed, it can't be categorically stated that the colour didn't bind to the grapheme. The results nonetheless show that the synaesthetic Stroop effect is strongly modulated by attention, which is in line with other research on GC synaesthesia and attention (Laeng, Svartdal, & Oelmann, 2004; Sagiv, Heer, & Robertson, 2006; Ward, Jonas, Dienes, & Seth, 2010).

One way in which graphemes can be presented for longer durations than masking studies without them being consciously perceived is through *visual crowding*. When a target or priming stimulus is surrounded by other distracters and viewed only with peripheral vision, they are harder to identify. Hubbard and colleagues used this method, presenting a target inducer digit surrounded by four crowding digits (Hubbard et al., 2005; Hubbard & Ramachandran, 2005). Both synaesthetes and control participants viewed the crowded digit in black font, controls also completed trials where the target was displayed in real colour (coloured, not black font). The task was to identify the central crowded grapheme. Three of the six synaesthetes were overall significantly better at this task than controls when the font was black, however controls



viewing the real colours were more accurate than synaesthetes. Synaesthetes also anecdotally reported experiencing colour, and using it to guide their decision (Ramachandran & Hubbard, 2001). Therefore, the synaesthetes colours did aid in the grapheme detection (at least for some synaesthetes), but not as well as real colour.

Phenomenology of synaesthetic experience triggered by crowded digits has been compared to accuracy measures (Ward et al., 2007). After identifying the central crowded grapheme, synaesthetes stated whether they saw the colour and grapheme, saw colour but no grapheme, saw the grapheme and no colour, or saw neither (guessing). Out of the 14 synaesthetes, six of the seven projectors and one of the seven associators saw colour. Furthermore, four of the projectors experienced colour for some trials in which the grapheme wasn't identified. This highlights the importance of recording phenomenology on a trial by trial basis. In this study, we shall explore this idea further.

The crowding technique used by Hubbard et al. (2005) allowed for the graphemes to be presented for longer durations of time than masking studies. However, all trials in which the participant moves their attention from the central fixation cross to the peripherally crowded target have to be removed, as the participant can look directly at the target thus rendering all crowding irrelevant. A more rigorous way of presenting peripherally crowded digits is through *gaze-contingent crowding* (GCC; also called *gaze-contingent substitution*). This utilises eye tracking which detects the participant's fixation throughout the presentation of the stimulus. Unlike basic crowding, where trials with a saccade towards the priming stimulus are removed, if the participants gaze moves towards the crowded prime, the prime is simply removed from view leaving only the crowding visible. By presenting the crowded prime on both the left and right of the monitor with participants aiming to fixate centrally, trials where a saccade is made can be retained as the prime always remains on screen.

It should be noted that although no ceiling effect was encountered in the Hubbard et al. (2005) study, the performance on this visual crowding detection task was still very high. In order for attention to be controlled more carefully, GCC can be designed to reduce objective identification performance to near chance levels. There is some debate as to how fully unconsciously presented peripheral stimuli can be processed; however, priming effects have been demonstrated for percepts which require more than low level visual processing, such as GCC presented emotive faces (Faivre et al., 2012; Kouider et al., 2011). This study will therefore use GCC to present digits to synaesthetes for long durations without them being consciously perceived.

*Continuous flash suppression* (CFS) is another technique which can be used to present stimuli without them being consciously perceived. Two separate images are presented side by side on the monitor. A mirror stereoscope controls how these images are viewed. The left eye only sees the left image on the monitor, the right eye the right image. When the images are aligned in the centre of each mirror, they fuse so that the participant perceives only one image. During trials, the dominant eye sees a continually changing high contrast image which suppresses the static image presented to the other eye. The image can be suppressed for long durations, several minutes in some cases (Tsuchiya & Koch, 2005). After a while, the suppressed image suddenly breaks through into conscious awareness, and this duration can be measured so that differences between suppressed stimuli can be investigated (Stein et al., 2011). This time until break through in CFS is called break through CFS (b-CFS). For example, it has been shown that upright faces 'break through' faster than inverted faces (Jiang, Costello, & He, 2007). This technique could be used to investigate the processing of graphemes suppressed from awareness. In the same way that upright faces break through faster than inverted faces, would a grapheme presented in its congruent colour break through faster than an

incongruently coloured grapheme? Another little investigated aspect of GC concurrents are the greyscale colours. The colours that GC synaesthetes experience are not always bright or prototypical, for example banana yellow. Other colours, such as greenish browns or even greyscale colours like dark grey can be experienced. Some graphemes may have no colour at all. If a grapheme has a ‘colourful’ concurrent colour, would it be break through CFS to conscious awareness faster than a grapheme with a greyscale concurrent?

Not only do synaesthetes have their own colour palette (Simner et al., 2005) but there are phenomenological differences in how or where they experience the colour. The projector sub-group see the colour on the grapheme itself, or in close proximity to it outside of their person (Dixon et al., 2004). Associator synaesthetes see the colour in their mind’s eye, or have more a sense of knowing that it is a particular colour rather than actually seeing it (Dixon et al., 2004). Projectors report experiencing more subjective colours under brief viewing conditions than associators do (Ward et al. 2007; 2010), although the colours are not always the ones that are normally associated with that grapheme (Ward et al. 2007). This suggests differences between projector and associator synaesthetes in the conscious perception of colour. It has also been proposed that the differences between projector and associator synaesthetes could be due to differences in mental imagery ability (Simner, 2013). As mental imagery abilities are highly variable (Marks & Marks, 1973) it may be that synaesthetes with low mental imagery would only have a sense of “knowing” the concurrent colour whereas those with high mental imagery abilities would have more visual properties to their concurrent (Simner, 2013). We therefore considered it necessary to explore the relationship between colour and accuracy more thoroughly; do the colours actually help to detect graphemes and is this linked to mental imagery abilities?

Questionnaires have been designed to measure the differences in GC synaesthesia phenomenology. We used the Coloured Letters and Numbers (CLaN) (Rothen, Tsakanikos, et al., 2013) and revised Rouw and Sholte Projector-Associator (R-RSPA) (Anderson & Ward, 2014) questionnaires to explore how the synaesthetes experience and use colour, and to explore how the behavioural measures relate to differences in experience.

In this study, the scope of subliminally presented graphemes' ability to bind with a colour will be investigated. In Experiment 1, GCC will be used to subliminally present digits to test whether they A) influence behavioural responses, B) influence congruent or incongruent colour responses, and C) elicit colours for the synaesthetes. In Experiment 2, CFS will be used to investigate whether the following factors influence breakthrough durations: A) the concurrent colour of achromatically presented graphemes; B) the congruency of a graphemes colour, and C) colour words presented in congruent or incongruent colours.

### **5.3 EXPERIMENT 1**

Three tasks were made using the GCC technique, each using a similar set up and the same priming stimuli. The Digit Priming Task (Experiment 1A) presented a prime digit (e.g. 4) in the periphery followed by a supraliminal central probe digit (e.g. 3). The participant was required to decide whether the centrally presented target was  $<5$  or  $>5$ . This enabled measures of repetition priming (e.g. 3 presented as both prime and probe) and response priming (the prime and probe being numerically different but requiring the same response). This task was performed by both synaesthetes and controls to determine whether the prime was actually being processed. A second task, Digit-Colour Priming (Experiment 1B), was conceptually similar with a digit prime but the central probe was a colour patch (corresponding to the colour of a digit) and the colour

had to be classified. Only synaesthetes performed this task, as this was to test whether the grapheme was triggering the concurrent colour. The third task, the Digit-Detection task (Experiment 1C), involved presenting only the crowded digit. Participants had to decide what digit it was and, if they were synaesthetes, report any colour experiences. This was to measure whether the procedure was successful in giving rise to low awareness of the prime (preferably near chance levels) and, further, to see if synaesthetes were able to report colours for graphemes that were not consciously detected. This task was run on both synaesthetes and controls.

## **Method**

### **Participants**

Twenty synaesthetes (aged 21–56,  $M = 34.85$ ,  $SD = 11.01$ , 14 female) and 22 control participants (aged 19–34,  $M = 22.95$ ,  $SD = 4.61$ , 16 female) completed the GCC experiments.

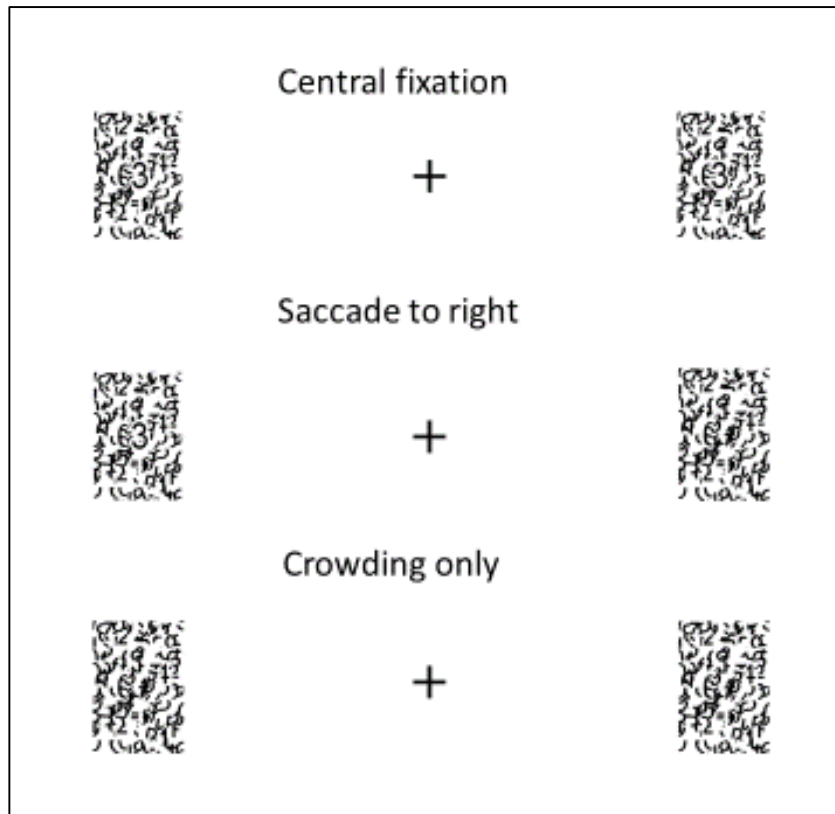
### **Priming Stimuli**

For the GCC technique, two almost identical images are made, one containing the priming stimulus, and the other only the crowding. When the participant's gaze is roughly around the fixation cross, the image containing the prime is displayed, Figure 5.1 is an example prime image. If their gaze is diverted outside the (predefined) central viewing area, the presented image changes to the one only containing the crowding (and fixation cross). Since the images are almost identical, the participant does not notice the image change. The background crowding images was generated by scrambling an image which contained digits 0–9 in Arial black font on a transparent background. The image

was scrambled in an 8 by 10 matrix, then a second layer was added with a random offset. The crowding was presented at  $9^\circ$  from centre (to the edge of the crowding), and the crowding itself was about  $2^\circ$  in width. The digit was therefore presented within the  $11^\circ$  suggested angle (Ramachandran & Hubbard, 2001). Primes were black digits (1, 2, 3, 4, 6, 7, 8 or 9) with white halos, the digit itself being roughly 18-25 pixels wide. For each digit, four crowding/prime and crowding image sets were made.

The program was made using Eyelink. For the GCC priming display, an image with one digit (the same at either side) was layered on top of digit crowding with a fixation cross presented centrally. If the participant viewed outside the central window (750 (w) by 1022 (h) pixels) then the crowding only image would be presented on the corresponding side of the screen. At least one prime digit was therefore present on screen at all times and trials with a horizontal saccade didn't need to be removed (see Figure 5.1). Between trials the calibration had to be corrected for any drift (slight movement of the participant), so the participant was asked to look at the central fixation dot between trials, which changed to a cross during trials.

During each trial, the participant was asked to look at the fixation cross whilst the crowded digit primes were presented for 2500ms, then the crowding only version of the image was presented for 100ms to prevent after images. Target images differed between blocks.



**Figure 5.1.** Example gaze-contingent priming images. When fixation is roughly central, a prime is displayed at both the left and right. If gaze moves towards either side, the corresponding prime is removed leaving only the crowding visible. After presentation of the prime for 2500ms, the crowding only image is shown for 100ms.

### Synaesthetes' colours

Each synaesthete completed the Synaesthesia Battery (Eagleman et al., 2007) before attending the experiment sessions. This allowed the average RGB values for the colours experienced by the synaesthetes for each grapheme to be calculated and used for creating the individually tailored experiments. Synaesthetes also completed the CLaN and R-RSPA in advance for investigation of relationships between phenomenological and behavioural measures.

## **Overall Procedure**

Participants sat 65 cm from the 21” Sony Trinitron CRT monitor (using a chin rest). Screen resolution was 1280 by 1024, refresh rate 60 Hz. Participants performed a 9 point calibration before each experiment. Eye tracking was performed with an Eyelink II (SR-Research, Ontario) headset with 500Hz pupil position detection. The experiment was made using Experiment Builder. A Cedrus response box marked with the appropriate colours or numbers for the particular testing block was used. Participants were given specific instructions depending on which block they were completing.

Eprime was used for response practice trials completed prior to the experiments which contained multiple response options (Experiments 1B and 1C) to train participants on which button to press without looking at the Cedrus box. During training trials, participants simply had to press the button which corresponded to the digit/colour patch on the screen. No priming stimulus was shown. Feedback was given after each trial (20 trials), but this is not included in the analysis.

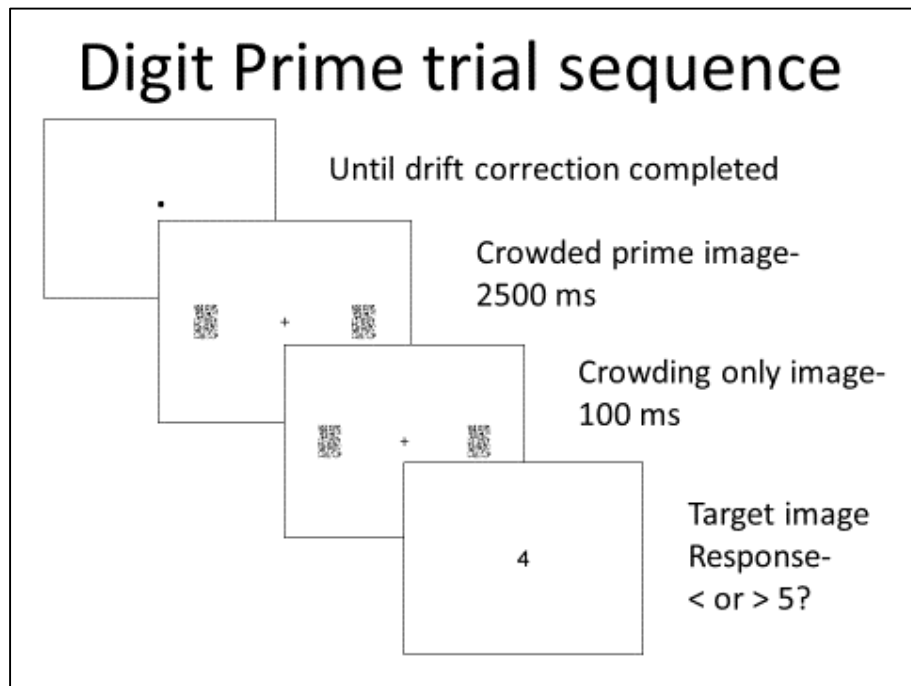
The order of experiments 1A and 1B was counterbalanced. However, 1C always happened last in case participants became more aware of the peripherally presented digits over time (although the digit prime set for 1C (1, 4, 6, 9; or 2, 3, 7, 8) was also counterbalanced).

### **5.3.1 Experiment 1A**

This experiment measures repetition and response priming of digits, presented under GCC conditions, in synaesthetes and controls.



## Procedure



**Figure 5.2.** Trial sequence for Experiment 1A. Due to shrinking of stimuli for the diagram, it is not possible to see the digits within the crowding.

The digit priming task contained 160 trials. Every priming digit (1, 2, 3, 4, 6, 7, 8 & 9) was paired with each target digit twice (16 x 8 trials) with an extra 32 repetition priming pairs (for example, 1 being paired with 1). After the crowded prime digit was shown, a target digit was presented and the participant had to indicate if the number was greater or less than five through a 2AFC button press as quickly and accurately as possible. This task was used as it is a sensitive measure of digit priming (Naccache, Blandin, & Dehaene, 2002). Completion of this task took approximately 25 minutes and participants had a short break after half the trials. Figure 5.2 shows the trial sequence for the digit priming experiment.

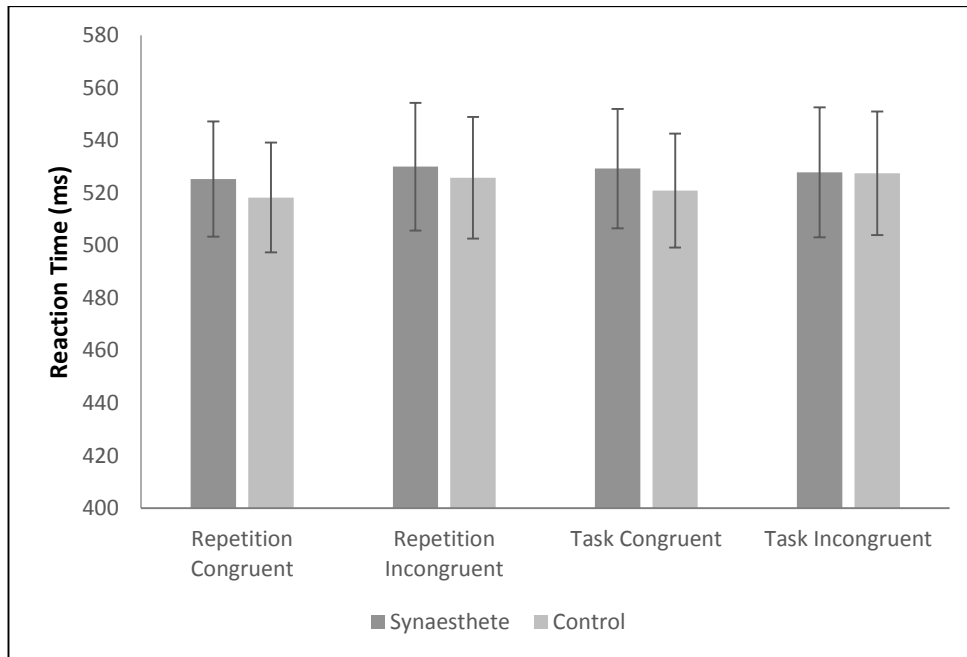
## Results

The data from all experiments was treated in the same manner. For RT data, outliers ( $\pm 2SD$ ; 217 trials) were removed, calculated using the overall RT mean for each participant's accurate trials. This was due to the large individual variation in break though time for the CFS experiments.

To determine whether repetition priming decreased RTs, a two (repetition priming; congruent or incongruent) by two (group; synaesthete or control) way ANOVA with within subjects for repetition priming was conducted. The main effect of repetition priming was not significant, ( $F(1, 40) = 2.07, p = .16$ ), with similar accurate response RTs in the congruent and incongruent trials. The main effect of group was not significant ( $F(1, 40) = 0.03, p = .86$ ) with similar RTs for synaesthetes and control participants. The interaction was also not significant ( $F(1, 40) = 0.11, p = .75$ ). Showing the same digit prime and target therefore didn't reduce RTs and suggests that the digits were not processed enough to influence RTs in a repetition priming comparison. A Bayes factor was calculated to determine whether the results actually support the null hypothesis, or represent insensitive data (Dienes, 2011). If the value is less than 0.33 it supports the null hypothesis, greater than 3 supports the alternative and between these values the data is insensitive to distinguish between the hypotheses. The SD for the calculation was taken from two studies which used the same task but with masking instead of GCC. They found a priming effect of 16 ms difference between task congruent and incongruent responses (Naccache & Dehaene, 2001) or repetition priming congruent or incongruent responses (Reynvoet & Ratinckx, 2004). The 16ms will therefore be used as the SD of a half normal distribution for our Bayes factor analysis. A value of 0.95 was obtained which suggests that no conclusions can be taken

from the results (calculated from; mean difference = 5.595,  $SEM = 31.69$  and  $SD = 16ms$ ).

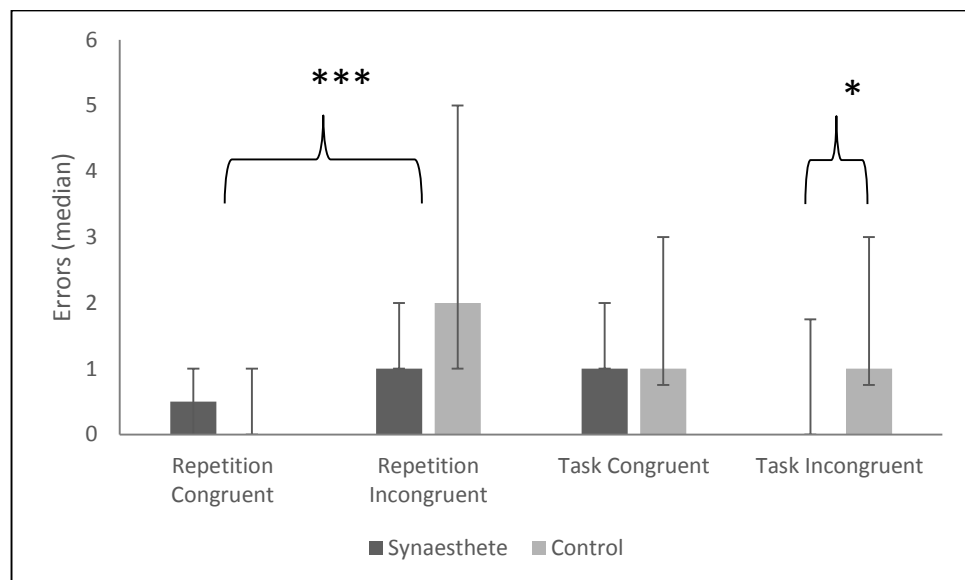
Next, whether there was an effect of task priming (where the prime digit corresponded to the trial response, for example a primed digit 2 would elicit the same task response as a target digit 4 and therefore be task congruent) on accurate trial RTs was investigated. A two (task priming; congruent or incongruent) by two (group; synaesthete or control) mixed ANOVA was conducted. The main effect of task priming was not significant ( $F(1, 40) = 0.50, p = .49$ ) with similar RTs for task congruent and task incongruent priming. The main effect of group was not significant, with similar RTs for synaesthete and control participants ( $F(1, 40) = 0.02, p = .90$ ) and the interaction was also not significant ( $F(1, 40) = 1.19, p = .28$ ). Therefore, there was no effect of priming on RTs, which can be seen in Figure 3. A Bayes factor of 0.94 suggests that no conclusions can be taken from the results (calculated from: mean difference = 4.35,  $SEM = 32.62$  and  $SD = 16ms$ ). RT priming effects are therefore not expected in Experiment 1B.



**Figure 5.3.** Mean reaction times for synaesthete and control participants in the digit priming task, for both repetition priming and task priming comparisons. Error bars represent +/- 1SEM.

Next the number of errors made was analysed, however the data was skewed so non parametric analysis was conducted. To determine whether repetition priming influenced the number of errors, a related samples Wilcoxon Signed Rank Test was conducted, finding that there was a significant difference ( $Z = 432.50$ ,  $p < .001$ ,  $r = .64$ ) between repetition congruent and incongruent trials. Independent Samples Mann-Whitney U tests found no significant difference when comparing synaesthete and control groups error rate for repetition congruent ( $U = 186.50$ ,  $p = .35$ ,  $r = .15$ ) or repetition incongruent ( $U = 288.50$ ,  $p = .08$ ,  $r = .27$ ) trials. Therefore although repetition priming was not evident in the RT data, it was in terms of error rates. This shows that repetition priming did occur, and that the digits were processed to a degree to influence behaviour.

For task priming error rates, first a related samples Wilcoxon Signed Rank Test was conducted finding no significant difference between task priming congruent and incongruent trials ( $Z = 90.50$ ,  $p = .37$ ,  $r = .14$ ). When Independent Samples Mann-Whitney U tests were conducted, although no significant difference was found between synaesthete and control participants for task congruent trials ( $U = 224.50$ ,  $p = .90$ ,  $r = .02$ ) there was a significant difference between them in task incongruent trials ( $U = 298.50$ ,  $p = .04$ ,  $r = .32$ ) with more errors being made by the control group than synaesthetes, as can be seen in Figure 5.4. Therefore, although task priming was not evident in the RTs, there was an effect when looking at error rates.



**Figure 5.4.** Median error rates in the digit priming task for synaesthete and control participants, with both repetition priming and task priming comparisons. Error bars represent interquartile range.

As it is important to explore the relationship between behaviour and phenomenology across variations of GC synaesthetes, we conducted Spearman's Rho correlations for the synaesthetes between the questionnaire and experiment measures.

As can be seen in Table 5.1, there are significant correlations between the CLaN automaticity and attention measure and all of the error rates, both congruent and incongruent. This relationship was negative, therefore as the error rate increased, this was related to a reduced perception of automaticity and increased requirement for attention for synaesthetic colour experience. There were also significant correlations for all of the RTs and the longitudinal measure of CLaN, again negative, with longer RTs being associated with synaesthetic experiences which haven't changed intensity (either stronger or weaker in the past). There was no clear relationship between projector and associator dimensions and the digit priming measures. This is interesting, as it shows that the projector/associator divide most commonly researched is not necessarily the most important for behavioural variability. It should be noted that as the correlations in this paper are not corrected for multiple comparisons, they are exploratory in nature and would need to be corroborated by further research.

**Table 5.1.** Spearman's Rho correlations between the reaction time (ms) and error (number) data and the CLaN and M-RSPA questionnaire dimensions for the synaesthetes.



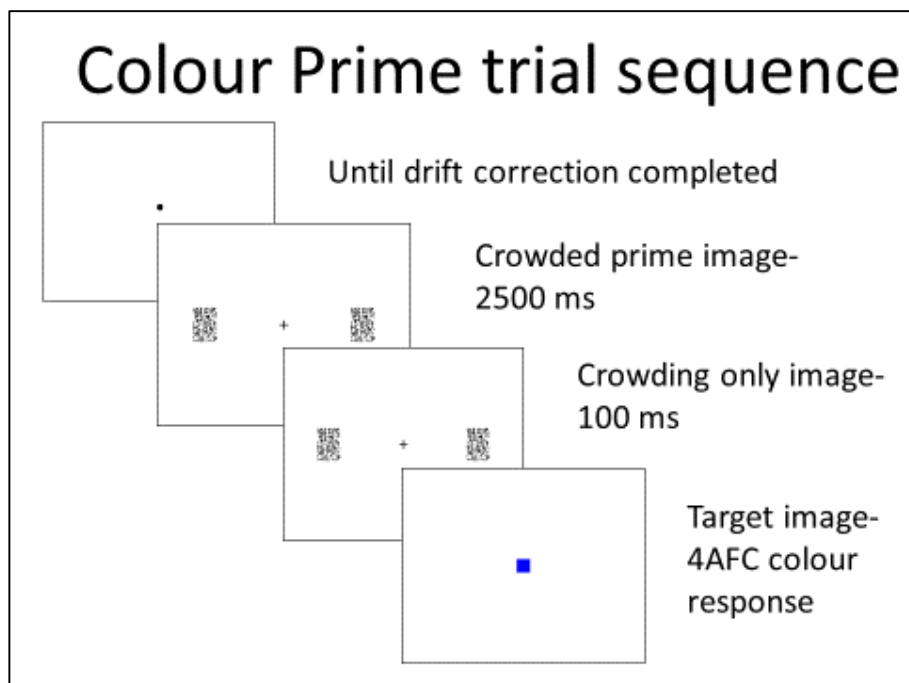
### 5.3.2 Experiment 1B

This experiment measures priming of colours by digits presented under GCC conditions in synaesthetes only.

#### Stimuli

The same digit priming stimuli were used as in Experiment 1A, however the targets were colour patches created for each individual synaesthete using the RGB values taken from the Synaesthesia Battery results. Out of the digits 1,2,3,4,6,7,8 and 9, the four digits which had concurrent colours most closely matched to red, green, blue and yellow were chosen. Target colour patches were made using the RGB values for these colours, and the digits they correspond to were included in the study for that individual synaesthete.

#### Procedure



**Figure 5.5.** Trial sequence for Experiment 1B. Due to shrinking of stimuli for the diagram, it is not possible to see the digits within the crowding.



This task contained four numbers and their corresponding synaesthetic colour patch.

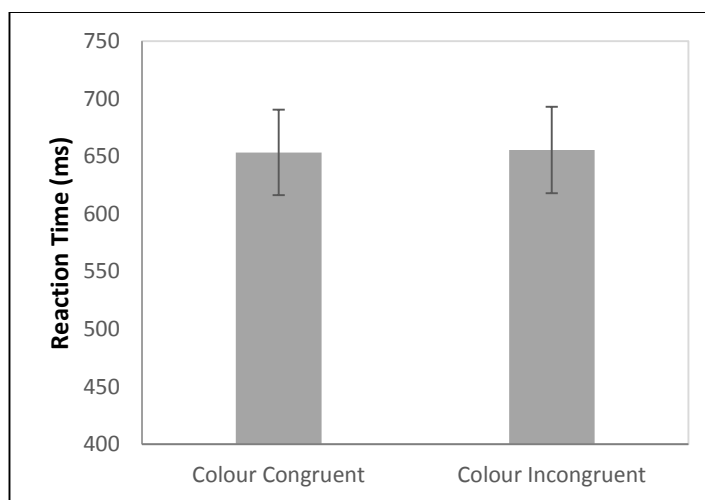
There were 80 trials, each digit being paired with each colour patch four times (4 x 16) with an extra 16 repetition priming pairs, four for each colour digit (4 x 4). Participants viewed the priming digit stimuli for 2500ms, then the crowding only image for 100ms, and finally an individualised colour patch in congruent or incongruent pairings.

Participants had to indicate the colour of the target through a 4AFC button press.

Completion of this block took roughly 15 minutes. Figure 5 shows the trial procedure.

## Results

The RT outliers were removed before analysis ( $\pm 2SD$ ; 57 trials). To test whether the prime digit influenced RTs (in accurate trials) for colour target response, a paired samples t-test was conducted. This showed no significant difference between congruent and incongruent trials ( $t(19) = -0.25, p = .80$ ). A Bayes factor was calculated, and at 0.57 suggests that no conclusions can be taken from the results (calculated from; mean difference = 2.19,  $SEM = 8.68$  and  $SD = 16ms$ ).



**Figure 5.6.** Mean reaction times for synaesthetic colour congruent and incongruent trials. Error bars represent  $\pm 1SEM$ .

To compare the error rates, a related samples Wilcoxon Signed Rank Test was conducted and found no significant difference between errors in congruent (*Median* = 0, *range* 0-4) and incongruent (*Median* = 0, *range* = 0-4) trials ( $Z = 35.50$ ,  $p = .41$ ,  $r = .18$ ). Colours were therefore not primed by the digits either in terms of RTs or errors.

The behavioural measures were compared to the CLaN and R-RSPA questionnaire responses. Similar relationships were found to those in Experiment 1A. There was a significant negative relationship between the CLaN longitudinal change and the reaction times, with longer reaction times being associated with lower longitudinal change. There was also a significant negative relationship between CLaN automaticity and attention and the congruent colour error rate, with increased error rates being associated with lower automaticity increased requirements of attention, though the correlation with the incongruent error rate was not significant. Similarly to Experiment 1A, there was no significant relationship between the behavioural measures and projector/associator values. Between the two tasks, a similar pattern of correlations was found suggesting that rather than only looking at projector/associator divisions in behavioural studies, the CLaN should be used more often as it captures other dimensions of GC synaesthesia phenomenology which relate to behavioural outcomes.

**Table 5.2.** Spearman's Rho correlations between colour priming reaction times (ms) and error (number of) rates and the CLaN and R-RSPA for synaesthetes.

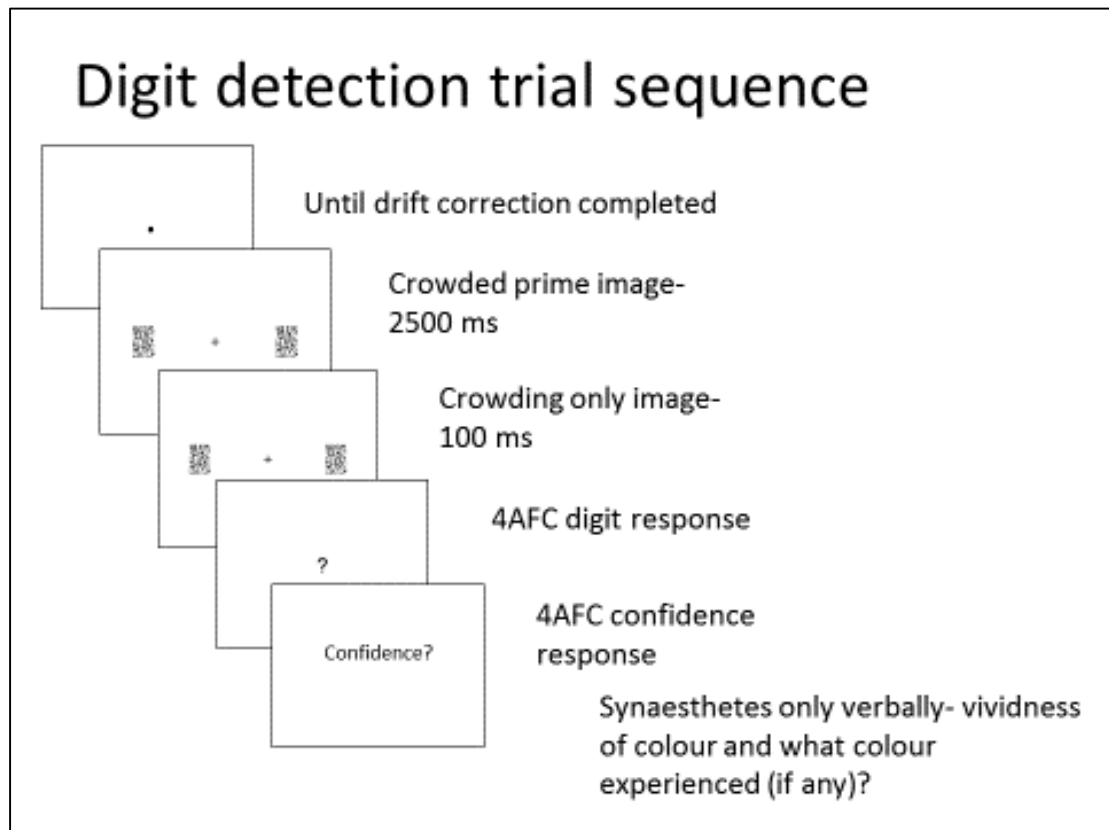
	Colour Congruent RT	Colour Incongruent RT	Colour Congruent Error	Colour Incongruent Error
<b>CLaN Localisation (N = 19)</b>	-.29	-.32	-.14	.00
<b>CLaN Automaticity/ Attention (N = 19)</b>	-.09	-.19	<b>-.82 ***</b>	-.14
<b>CLaN Deliberate Use (N = 19)</b>	.21	.15	-.45	.08
<b>CLaN Longitudinal Change (N = 19)</b>	<b>-.49 *</b>	<b>-.47 *</b>	.22	.04
<b>R-RSPA Projector (N = 19)</b>	-.01	-.02	-.32	.08
<b>R-RSPA Associator (N = 19)</b>	.22	.24	.23	-.16

$p < .05$  \*,  $p < .01$  \*\*,  $p < .001$  \*\*\*

### 5.3.3 Experiment 1C

This experiment presented digits under GCC conditions and measured participant's awareness of the digit (synaesthetes and controls) and colour phenomenology (synaesthetes only).

## Procedure



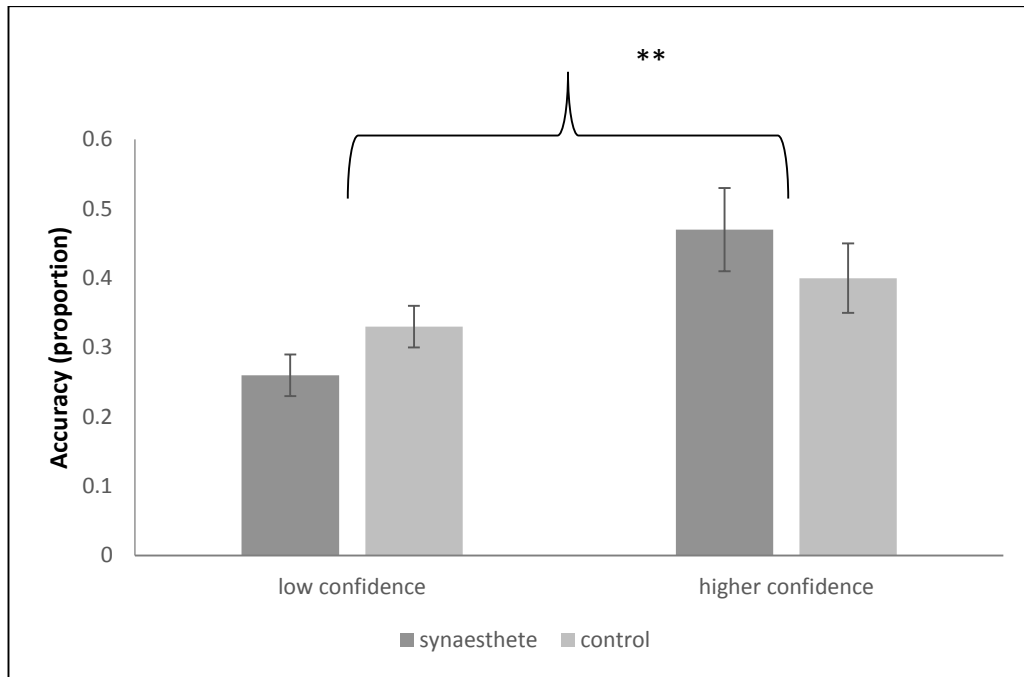
**Figure 5.7.** Trial sequence for Experiment 1C. Due to shrinking of stimuli for the diagram, it is not possible to see the digits within the crowding.

Next we tested whether participants could actually detect what digit was being presented peripherally and if so, for synaesthetes, what associated colour experiences they had. In the digit detection task, there were 40 trials separated into two blocks of 20 trials (10 of the control participants only completed one block). The same crowded images as in the Digit Priming task (Experiment 1A) were used, however only four were in each block (1, 4, 6 and 9; 2, 3, 7 and 8). The digit prime image was presented for 2500ms followed by the crowding only version of the prime for 100ms in line with the priming tasks; however, after that a question mark was presented (see Figure 5.7).

The participant had to indicate which digit had been present in the crowding, after which the word ‘confidence?’ appeared until they stated how confident they were in their answer. For these responses, 4AFC button presses were used to choose their confidence rating, the options were 25%, 50%, 75% or 100%. It was pointed out to participants that 25% represented chance. Participants were encouraged to try their hardest and use any inkling to guide their decision. After each trial, synaesthetes were also asked to rate verbally on an eleven-point Likert scale; the vividness of any colour experience (0 = no colour, 10 = extremely vivid); what colour they experienced if they gave a rating of one or higher for vividness. Each block lasted roughly five minutes for controls and eight for synaesthetes.

## Results

Low objective accuracy would demonstrate that any effects (if RT differences had been measured) were due to preconscious grapheme and colour binding. To test this, a two (confidence; low (25 %) and higher (> 25 %)) by two (group; synaesthete or control) mixed ANOVA was conducted on the percentage accuracy of responses. One synaesthete never gave a confidence response greater than 25% and therefore was not included in this analysis. The main effect of confidence was significant ( $F(1, 39) = 10.00, p = .01$ ) with higher levels of accuracy for higher confidence compared to low confidence trials. The main effect of group was not significant ( $F(1, 39) = 0.01, p = .98$ ) with synaesthete and control participants having similar levels of accuracy, and the interaction was also not significant ( $F(1, 39) = 2.99, p = .09$ ). Figure 5.8 shows this comparison. Synaesthetes and controls were therefore comparable in their responses: one group was not more accurate or confident than the other. Differences in behaviour during Experiment 1A were therefore not driven by controls being more aware of the digits than the synaesthetes.



**Figure 5.8.** Mean accuracy for low confidence and higher confidence trials for synaesthete and control participants. Error bars represent  $\pm 1$ SEM.

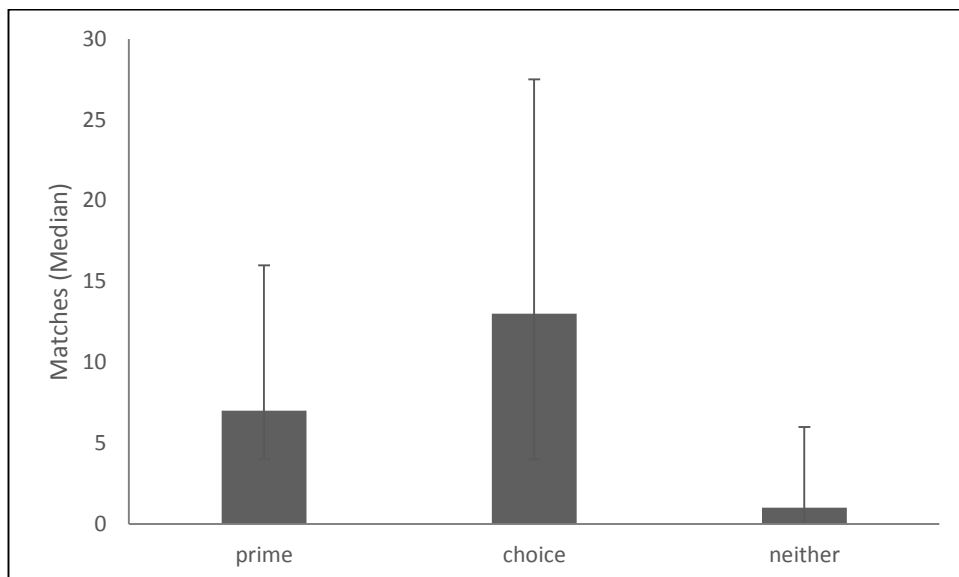
The rest of the analysis on Experiment 1C is on synaesthetes only. If colour occurs from early visual processes, then if colour is experienced it could be expected to improve detection accuracy, as it would give an alternative identification method other than digit detection. Alternatively, if colour is due to attention driven mechanisms then it could be assumed that in trials where colour is experienced, the grapheme has already been detected and identified leading to the colour perception, and these trials should be more accurate than trials where no colour is experienced. Both mechanisms expect a relationship between colour and accuracy. To test whether there were differences in accuracy driven by colours experienced, a related samples Wilcoxon Signed Rank Test compared accuracy for trials in which the participant reported no colour (*Median* = 0.32, *range* = 0.00-0.50), compared to trials in which colour was reported (*Median* = 0.34, *range* = 0.00-0.68). There was no difference in accuracy between the trials ( $Z =$

71.00,  $p = .53$ ,  $r = .16$ ) for the 16 synaesthetes who experienced colours for some (but not all) trials. Therefore, colours don't appear to be linked to accurate recognition of the grapheme.

Next, the relationship between colour and confidence was analysed, by conducting a related samples Wilcoxon Signed Rank Test which found a significant difference ( $Z = 120.00$ ,  $p = .01$ ,  $r = .67$ ) between the confidence rating, with higher confidence levels reported for trials in which a colour was experienced (*Median* = 52.08, *range* = 25.83-60.42) than those where no colour was experienced (*Median* = 31.39, *range* = 25.00-100.00).

Therefore, experiencing colour increased the confidence that a synaesthete had in their response, but didn't improve their accuracy or metacognition. As we expected colours to improve accuracy, which was not found, were the colours the synaesthetes actually related to the primed digit? Any colour which had been experienced had been noted at the end of each trial, and this was then compared to the colours which had been recorded using the Synaesthesia Battery. We compared the colours for the digit which the synaesthete had chosen for the primed digit presented in the crowded display, and the colour for the digit which the synaesthete had selected in their digit choice response. The coding was completed by the experimenter. A very liberal coding scheme was used, where a match was recorded if it was similar in general colour (so orange would be considered a match to red) or in luminance (navy blue would be a match for black). The main reason for this is the potential for language and RGB value discrepancies. The colour had been 'named' by the researcher when recording what colour was associated by that synaesthete for each digit when viewing the synaesthete colour palette on the Synaesthesia Battery, and this was compared to a named colour given by the synaesthete at the end of a trial. The lenient colour coding scheme allowed for this

discrepancy. Related samples Wilcoxon Signed Rank tests were conducted to compare the number of trials in which there was; a match between the prime and reported colour; a match between the chosen digit and reported colour; no colour match. The significance level considered to demonstrate a significant difference was reduced to adjust for the multiple comparisons, to  $p < .02$  being considered as significant (the general significance value of .05 divided by the number of comparisons;  $.05 / 3 = .016$ ). There was a significant difference between the number of trials in which there was a prime match and choice match ( $Z = 105.00, p = .001, r = .80$ ), between a prime match and no match ( $Z = 6.00, p = .01, r = .074$ ) and between choice match and no match ( $Z = 4.00, p = .001, r = .83$ ). The colour was more likely to match the colour for the digit they chose, rather than the primed digit, as seen in Figure 5.9. Although there were far fewer colours reported which didn't match either the prime or the response, it is interesting that colours were experienced at times which bore no relation to either the primed or chosen digit.



**Figure 5.9.** Median number of colour matches for the prime digit, chosen digit or neither. Error bars represent the interquartile range.



The relationship between the accuracy, confidence and colours experienced were compared to the CLaN and R-RSPA values. This would inform us whether particular types of synaesthetic phenomenology increase accuracy or confidence in detection. The associator R-RSPA measure was significantly correlated with all of the colour experiences during the experiment, this was a negative relationship with higher numbers of colours or vividness of colours being related to lower associator values. The projector dimension of the R-RSPA was significantly positively related to the vividness of colour perceived, with greater vividness being associated with higher projector values. CLaN deliberate use was significantly positively related to vividness, number of colours overall, and choice match so that more colour experience was associated with higher deliberate use of synaesthetic colour in everyday life by the synaesthete. CLaN automaticity and attention was significantly correlated with prime and choice match, with higher match numbers being associated with higher automaticity. When considering automaticity and attention with the significantly higher number of choice matches compared to prime matches for colours, it appears that the colours may be experienced automatically, but after the participant thought of the number rather than before. It is interesting that the confidence levels were higher for trials in which a colour was experienced considering that it matched the chosen digit rather than prime digit more often.

**Table 5.3.** Spearman's Rho correlations between accuracy, confidence, vividness and number of colours for synaesthete participants and the CLaN and R-RSPA measures.

	Accuracy (average all trials)	Confidence (% average for all trials)	Vividness (average for all trials, range; 0-10)	Number colours (range; 0 – 40)	Number Prime Match (number of)	Number Choice Match (number of)
<b>CLaN Localisation</b>	.11	.15	.24	.31	.16	.23
<b>CLaN</b>	-.23	.16	.33	.38	<b>.51 *</b>	<b>.50 *</b>
<b>Automaticity/ Attention</b>						
<b>CLaN Deliberate</b>	-.15	.17	<b>.61 **</b>	<b>.59 **</b>	.49	<b>.50 *</b>
<b>Use</b>						
<b>CLaN</b>	.11	-.01	.04	.25	.03	-.00
<b>Longitudinal Change</b>						
<b>R-RSPA Projector</b>	-.01	.20	<b>.48 *</b>	.40	.21	.31
<b>R-RSPA</b>	-.01	-.31	<b>-.61 **</b>	<b>-.65 **</b>	<b>-.53 *</b>	<b>-.56 *</b>
<b>Associator</b>						

$p < .05$  \*,  $p < .01$  \*\*,  $p < .001$  \*\*\*

## 5.4 EXPERIMENT 2

CFS allows two images to be presented simultaneously, a dynamic high contrast

Mondrian display and a static image. Only the dynamic Mondrian display is consciously perceived initially then the static image 'breaks through' into conscious awareness

(Tsuchiya & Koch, 2005). By measuring the time to breakthrough, influences of the

preconsciously viewed image on conscious detection can be investigated. Here we shall

be asking whether congruency of grapheme (or word) and font colour influences time until break through.

## **Participants**

In total, 24 synaesthetic (aged 18-56,  $M = 30.83$ ,  $SD = 10.64$ , 17 female) and 24 control participants (aged 19-44,  $M = 25.33$ ,  $SD = 5.61$ , 17 female) took part. In Experiment 2A, there were 21 synaesthetic participants and 21 control participants. For Experiment 2B there were 19 synaesthetic participants and 19 control participants. Experiment 2C was completed by 22 non-synaesthetic participants, and no synaesthetes. Only 16 of the synaesthetes took part in both Experiments 2A and 2B, and 18 of the control participants took part in all of Experiments 2A, 2B and 2C. Experiment order was counterbalanced.

Seventeen of the synaesthetes (who took part in any of 2A or 2B) had taken part in the Experiments 1A, 1B and 1C. Ten of the control participants (who took part in any of 2A, 2B or 2C) had taken part in Experiments 1A and 1C. This discrepancy is because of limitations in synaesthetes' colour palettes (for example if they had no greyscale concurrents then they were not suitable for Experiment 1A) and individual reaction to the CFS (if a participant failed to see the first 10 trials they were excluded from that study, but if they failed to consciously see a grapheme in one experiment, it did not mean they were not capable in another).

### **5.4.1 Experiment 2A**

This experiment was designed to test whether the colourfulness of the concurrent (whether it was colourful or greyscale) influenced the time it took for GC synaesthetes to consciously perceive the grapheme. Colour aids in breakthrough (Hong & Blake, 2009); therefore, if a grapheme is binding with its concurrent preconsciously, it would

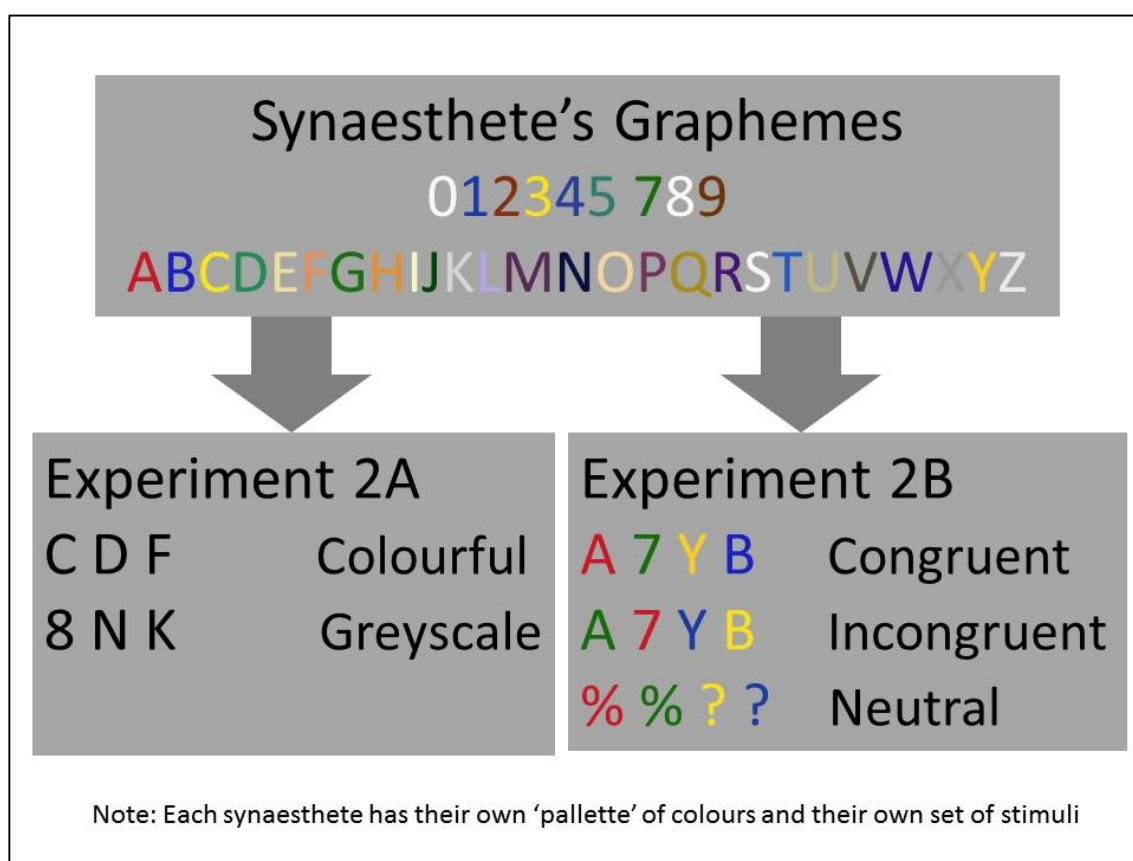
be expected to reduce time to break through if the concurrent is bright and colourful rather than greyscale. Control participants completed this task with graphemes either in black or the colours for the colourful graphemes.

### **Stimuli**

In the synaesthete version, a grey scale dynamic Mondrian display was used as the suppressing stimulus. The Mondrian patterns consisted of 500 greyscale blocks (maximum height or width of individual blocks being 80 pixels) randomly positioned (overlapping) within the 300 by 300 pixel square which changed at a rate of 10 Hz. The static image was a grey square on which a grapheme was presented in Arial with 100 font size. The graphemes were black and took 80 screens to reach full black (10 screens per second). The position of the Mondrian and stimulus images were dependent on calibration for each participant so that the images “fused” to form the perception of one square image. Graphemes were chosen for each synaesthete individually, depending on their responses to the Synaesthesia Battery (Eagleman et al., 2007). Figure 5.10 shows the colour palette for the digits 0-9 and alphabet. As can be seen, not all the graphemes evoked a colour, and some had grey scale concurrents which allowed for the experiment to be tailored for each individual synaesthete. Three graphemes which had a grey scale concurrent (the colour they evoked was black/ white/ grey) were chosen, if not enough were available then graphemes which evoked no colour were also used. Three graphemes which evoked a ‘colourful’ concurrent were also chosen, that is graphemes which triggered a more canonical colour, such as red, purple or turquoise. In the control version of this experiment, the participants viewed the graphemes in black font, or in the actual RGB value colours of the ‘colourful’ graphemes.

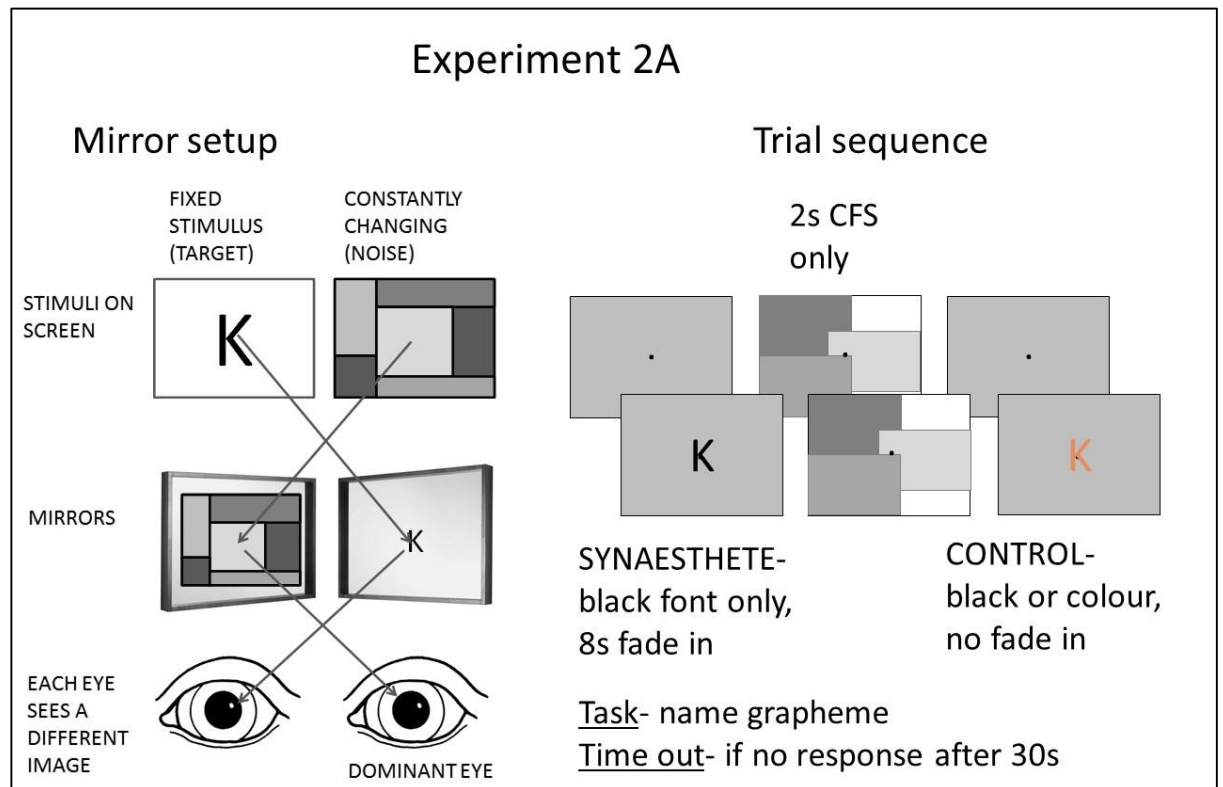
For control participants the suppressing Mondrian display was coloured and the graphemes were either black or in the colour of the ‘colourful’ graphemes experienced by their matched synaesthete (using RGB values). As the static image contained colour, it did not fade in view as it was not possible to fade in colour. A 5 pixel wide fixation dot was always present on each image to help keep images fused.

There were 96 trials (48 greyscale, 48 colourful), with all graphemes being presented in black font for the synaesthetes. The control participants viewed 48 in black and 48 in the colours of the colourful concurrents.



**Figure 5.10.** Example colour palette for a synaesthete, and how the graphemes were chosen for Experiments 2A and 2B of the CFS studies.

## Procedure



**Figure 5.11.** Experiment 2A set up and trial sequence.

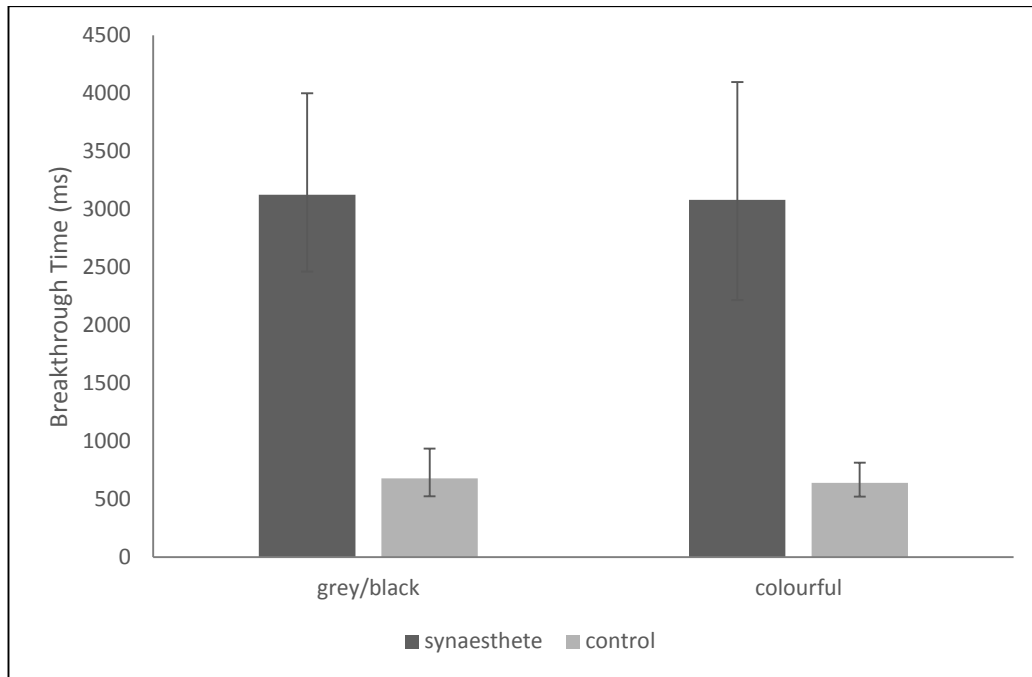
Participants sat 65 cm from a 21" CRT monitor (1280 by 1024 screen resolution, 60 Hz refresh rate), and viewed the images through a mirror stereoscope which allowed each eye to view a separate image on the monitor. The dominant eye viewed the grey dynamic Mondrian display, and the other eye viewed the static image. There was a 2000ms delay after onset of CFS before the stimulus was presented. Once the mirrors had been calibrated so that the two images fused, a practice trial was completed where the participant had to state the grapheme present on the monitor once they saw it. This triggered the microphone which recorded the time it took until 'break through' through a Creative E-MU 0202 sound card. The participant completed one or two practice trials to make sure they knew how to respond into the microphone. The experimenter

recorded the accuracy of responses and any errors with triggering of the microphone.

The experiment set up and trial sequence can be seen in Figure 5.11.

## Results

In order to test whether synaesthetic colours aid breakthrough into consciousness, RTs for correct trials were analysed. The excluded trials were either incorrect ( $N = 55$ ), delayed ( $N = 49$ ) time out ( $N = 34$ ) or outlying by  $\pm 2SD$  ( $N = 174$ ). First the synaesthete data was analysed: a related samples Wilcoxon Signed Rank Tests was conducted to compare RTs for grey scale or colourful concurrent graphemes, which was not significant ( $Z = 97.00$ ,  $p = .52$ ,  $r = .14$ ), as can be seen in Figure 5.12. Comparison of error rates between grey scale (*Median* = 0.00, *range* = 0.00-5.00) and colour (*Median* = 0.00, *range* = 0.00-2.00) the conditions was also not significant ( $Z = 16.00$ ,  $p = .24$ ,  $r = .26$ ). Therefore, the synaesthetic colours did not aid breakthrough into consciousness. As there isn't currently a non-parametric Bayes factor analysis, this cannot be calculated.



**Figure 5.12.** Median reaction times for breakthrough for greyscale or colourful graphemes, in both synaesthetes and controls. Error bars represent the interquartile range.

The control data was compared separately as the graphemes were not presented in exactly the same manner (they were not faded into view). A related samples Wilcoxon Signed Rank Tests was conducted to compare RTs for black or coloured graphemes, finding no significant difference ( $Z = 104.00$ ,  $p = .69$ ,  $r = .09$ ) as can be seen in Figure 5.12. However, when comparing the error rates between black and coloured graphemes, significantly more errors were made for the coloured (*Median* = 0.00, range = 0.00-19.00) compared to black (*Median* = 0.00, range = 0.00-5.00) graphemes ( $Z = 1.00$ ,  $p = .04$ ,  $r = .44$ ).

Next, to determine whether any phenomenological traits were related to performance on this task, correlations were calculated between responses of the



synaesthete participants during Experiment 2A and the questionnaire (R-RSPA and CLaN) values and can be seen in Table 5.4. There were no significant correlations with the projector/ associator dimensions, and only the deliberate use dimension of the CLaN was significantly associated with the greyscale error rate. The relationship was negative, with higher greyscale error rates being associated with lower levels of deliberate use.

**Table 5.4.** Spearman's Rho correlations between reaction times (ms) and error rates (number of) with the CLaN and R-RSPA questionnaires.

	Grey RT	Colour RT	Grey Error	Colour Error
<b>CLaN Localisation (N = 15)</b>	-.31	-.22	-.41	-.11
<b>CLaN Automaticity/ Attention (N = 15)</b>	-.13	-.24	-.05	-.07
<b>CLaN Deliberate Use (N = 15)</b>	-.39	-.35	<b>-.55 *</b>	-.12
<b>CLaN Longitudinal Change (N = 15)</b>	-.38	-.19	-.40	-.18
<b>R-RSPA Projector (N = 20)</b>	-.23	-.33	-.02	.08
<b>R-RSPA Associator (N = 20)</b>	.38	.29	.14	.17

$p < .05$  \*,  $p < .01$  \*\*,  $p < .001$  \*\*\*

#### 5.4.2 Experiment 2B

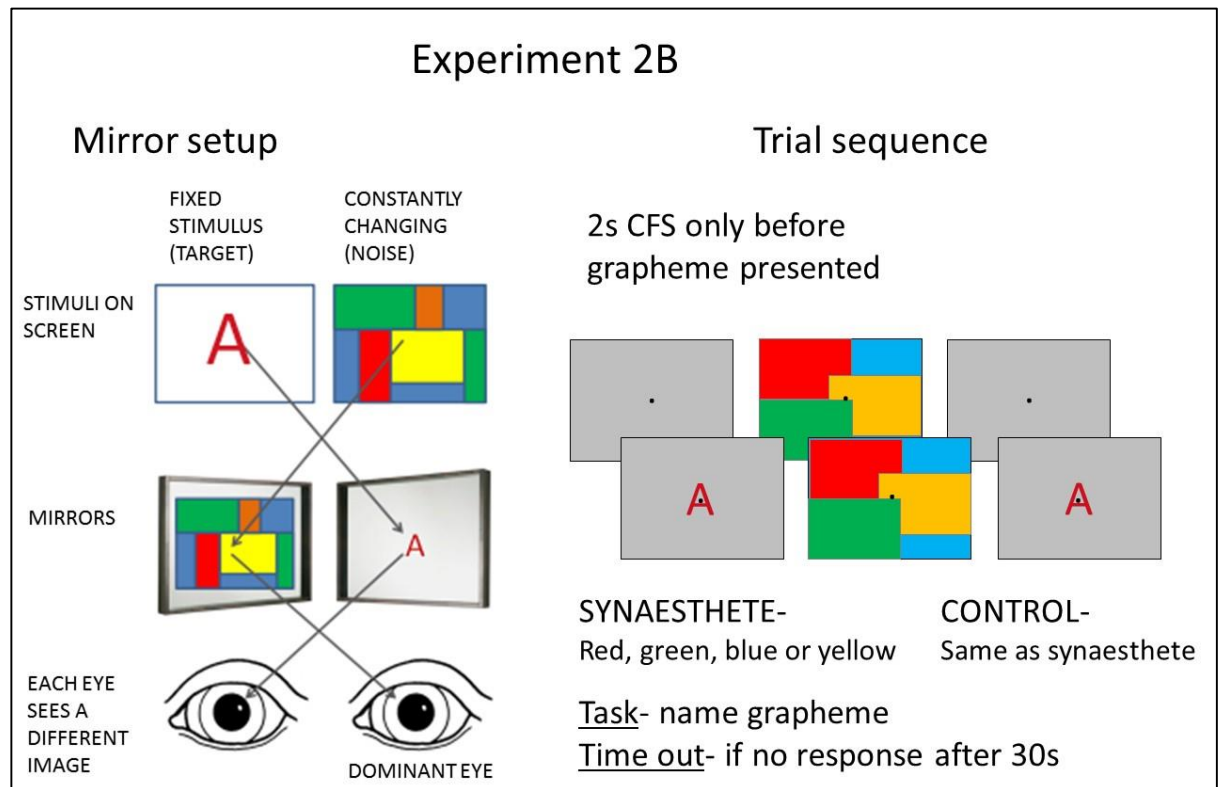
As a grapheme presented in black font suppressed from conscious awareness may not bind strongly enough with its corresponding grapheme to influence behaviour, we reasoned that presenting a grapheme in its concurrent colour may strengthen the binding of grapheme and colour, and therefore decrease breakthrough times in comparison to incongruent grapheme and colour pairings. In Experiment 2B, graphemes which evoked the colours red, green, blue and yellow were presented in their congruent or opponent

incongruent colour. Two grammatical symbols were also presented in red/ green or blue/ yellow. This way, the effect of colour congruency on breakthrough could be investigated.

### **Stimuli**

A dynamic coloured Mondrian display (300 by 300 pixels, 100 Hz made of 500 overlapping coloured blocks, each with a maximum height or width of 80 pixels) was presented to the dominant eye. The static image was a coloured grapheme presented on a grey square (300 by 300 pixel square size, Arial size 100 font). A 5 pixel wide fixation dot was always present on each image to help keep images fused. Graphemes were chosen from the Synaesthesia Battery results, with one grapheme being chosen which most closely evoked each of the colours red, green, blue and yellow. These graphemes were either presented in the correct colour (congruent, using the Synaesthesia Battery RGB values) or the opponent wrong colour (incongruent). Opponent pairings were used to maximise any potential interference (Nikolić et al., 2007). Two grammatical symbols which had no colour association were also chosen for each synaesthete and presented in red/green or blue/yellow. Figure 5.10 demonstrates how graphemes were selected for one synaesthete. There were three conditions; congruent colour (32 trials), opponent colour (32 trials) and neutral graphemes in opponent colour pairings (32 trials). Exact RGB values taken from Synaesthesia Battery (Eagleman et al., 2007) results. For each synaesthete, one control participant completed the same experiment as a control measure.

## Procedure

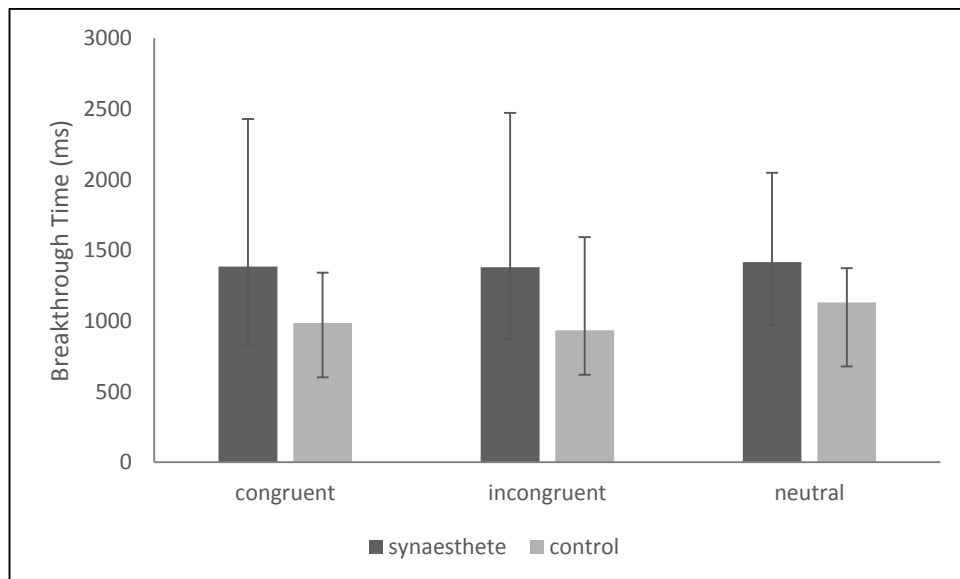


**Figure 5.13.** Mirror set up and trial sequence for Experiment 2B.

The set up was the same as in Experiment 2A, again the dependent measure was voice onset RT (ms) for the participant naming the grapheme or grammatical symbol ('break through'). Voice onset was used rather than key response to avoid the potential confound of priming between colours and response keys. There was 2s of CFS only (presentation of the Mondrian display) before the static stimulus was presented, Figure 5.13 shows the experiment set up. It was predicted that congruent pairings would break through faster than incongruent pairings.

## Results

In order to compare time to break through, the incorrect ( $N = 21$ ), delayed ( $N = 69$ ) time out ( $N = 104$ ) and outlying by  $\pm 2SD$  ( $N = 164$ ) trial RTs were removed. To test whether synaesthetes bind the grapheme and colour prior to awareness, the synaesthete group was compared to the control group. Independent samples Mann-Whitney U tests found no difference between the synaesthete and control group RTs for congruent ( $U = 117.00, p = .07, r = .30$ ), incongruent ( $U = 120.00, p = .08, r = .29$ ) or neutral ( $U = 137.00, p = .21, r = .21$ ) trials, as can be seen in Figure 5.14. When comparing the synaesthete only data, a related samples Wilcoxon Signed Rank Tests was conducted to compare RTs for congruent and incongruent graphemes which was not significant ( $Z = 93.00, p = .94, r = .02$ ). Therefore, the synaesthetic colours did not aid break through into consciousness.



**Figure 5.14.** Median reaction times for congruent, incongruent and neutral trials for synaesthete and control participants. Error bars represent the interquartile range.

The same set of analyses was conducted to compare the error rates of synaesthete and control participants, with independent samples Mann-Whitney U tests finding no difference between groups for congruent ( $U = 218.50$ ,  $p = .27$ ,  $r = .25$ ), incongruent ( $U = 171.00$ ,  $p = .80$ ,  $r = .09$ ) or neutral ( $U = 202.50$ ,  $p = .53$ ,  $r = .15$ ) trials, as can be seen in Figure 5.14. A related samples Wilcoxon Signed Rank Test was conducted on the synaesthete data only, comparing error rates for congruent and incongruent trials. This was not significant ( $Z = 5.00$ ,  $p = 1.00$ ,  $r = .00$ ) (*Median* = 0.00, *range* = 0.00-1.00 for both all groups and conditions other than control neutral which is *Median* = 0.00, *range* = 0.00-2.00).

The RTs and error rates were compared against the CLaN and R-RSPA as variability in phenomenology may have been masking differences in RTs. However, none of the behavioural measures were significantly correlated with the questionnaires, as can be seen in Table 5.5. This further confirms that the grapheme and colour didn't bind preconsciously.

**Table 5.5.** Spearman's Rho correlations between the median reaction times (ms) and error rates of the behavioural data, and the CLaN and R-RSPA questionnaires.

	Congruent	Incongruent	Neutral	Congruent	Incongruent	Neutral
	RT	RT	RT	Error	Error	Error
<b>CLaN</b>	.07	.14	.12	-.39	.37	-.11
<b>Localisation</b>						
<b>(N = 13)</b>						
<b>CLaN</b>	.16	.20	.04	-.39	.00	-.37
<b>Automaticity/</b>						
<b>Attention (N =</b>						
<b>13)</b>						
<b>CLaN</b>	-.05	-.00	.19	-.47	.03	-.06
<b>Deliberate Use</b>						
<b>(N = 13)</b>						
<b>CLaN</b>	-.21	-.27	-.42	.36	-.18	.03
<b>Longitudinal</b>						
<b>Change (N =</b>						
<b>13)</b>						
<b>R-RSPA</b>	-.02	.11	-.02	-.07	.31	-.01
<b>Projector (N =</b>						
<b>18)</b>						
<b>R-RSPA</b>	-.03	-.13	-.02	.17	-.04	.07
<b>Associator (N</b>						
<b>= 18)</b>						

$p < .05$  \*,  $p < .01$  \*\*,  $p < .001$  \*\*\*

### 5.5.3 Experiment 2C.

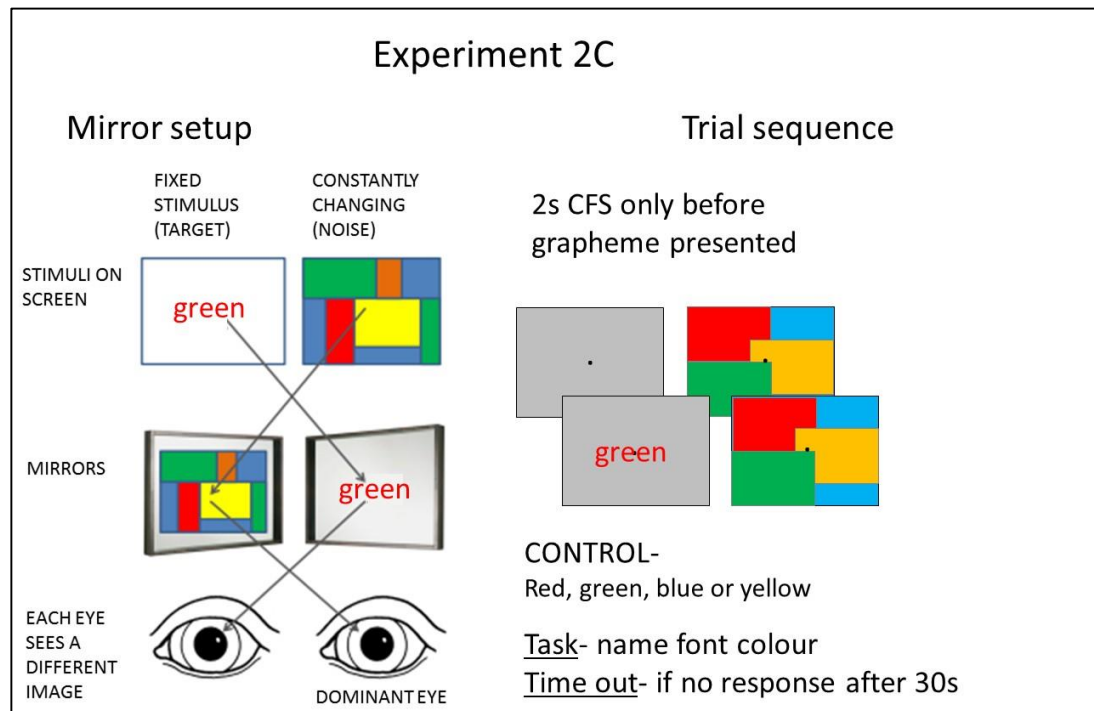
We also conducted a more traditional style Stroop task under CFS. This was to test if colour words and their font colours bind under CFS. If a word can bind with its colour,

we would know that a grapheme can be processed sufficiently to allow for grapheme-colour binding if such a process did indeed occur preconsciously in GC synaesthetes. It was predicted that congruent colour and word pairings would breakthrough into conscious awareness faster than incongruent pairs.

### **Stimuli**

A colour dynamic Mondrian display was presented to the dominant eye, as in Experiment 2B. Static stimuli were presented on the grey square as in Experiments 2A and 2B. The words *red*, *green*, *blue* and *yellow* were presented in the correct colour, or opponent colour. Two neutral words were also presented (crayon and paint) which were presented in red and green, or blue and yellow. Words were presented in Arial size 100 font. In each trial, the suppressing CFS display was shown alone for 2000ms before the static stimuli were presented. There were three conditions; congruent colour (32 trials), opponent colour (32 trials) and neutral words in opponent colour pairings (32 trials).

## Procedure



**Figure 5.15.** Experiment 2C CFS set up.

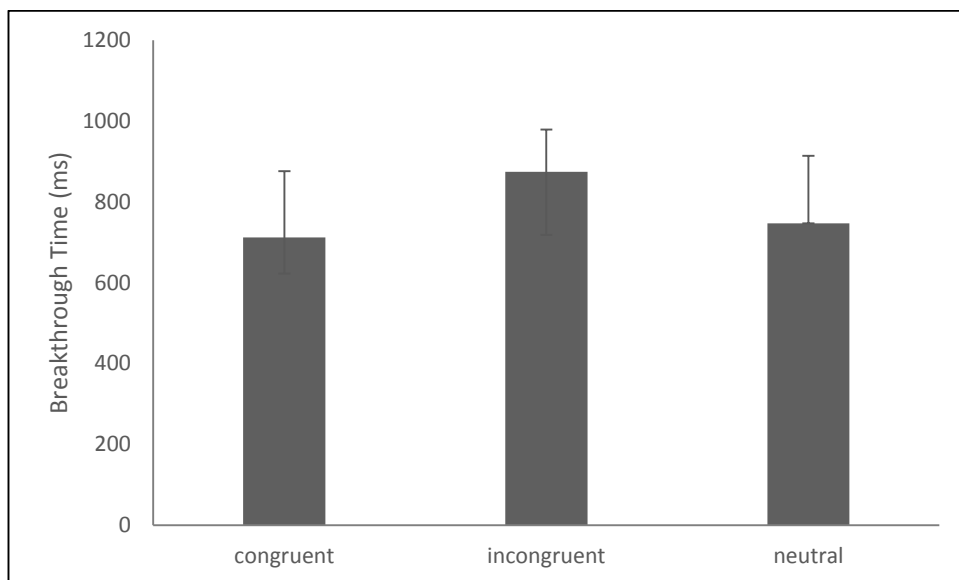
The procedure was the same as experiments 2A and 2B except that participants had to say the colour of the font when they consciously saw the word, triggering the microphone for voice onset RT (ms) to be recorded. The procedure can be seen in Figure 5.15.

## Results

RTs were calculated for correct trials, with the RTs for incorrect (N = 26), delayed (N = 85) time out (N = 33) and outlying by  $\pm 2SD$  (N = 75) trials being removed). To determine whether congruency of colour and word aided in breakthrough of the word, related samples Wilcoxon Signed Rank Tests were conducted. As three comparisons were conducted, the significance level accepted as representing significance was



adjusted accordingly ( $.05/3 = .016$ ). There was a significant difference between RTs for congruent and incongruent trials, with congruent trials breaking through faster ( $Z = 210.00, p = .01, r = .58$ ); between congruent and neutral trials, with neutral trials breaking through faster ( $Z = 197.00, p = .02, r = .49$ ); and between neutral and incongruent with neutral breaking through faster ( $Z = 25.00, p = .001, r = .70$ ). These differences can all be seen in Figure 5.16. The 162ms difference between congruent and incongruent RTs is substantial, and shows that colour words and font colours bind pre consciously to influence conscious detection.



**Figure 5.16.** Median reaction times for congruent, incongruent and neutral words. Error bars represent the interquartile range.

Next, error rates were compared, also using related samples Wilcoxon Signed Rank Tests and an adjusted significance level ( $p = .016$ ). There was a significant difference between congruent (*Median* = 0.00, *range* = 0.00-1.00) and incongruent (*Median* = 1.00, *range* = 0.00-4.00) trial error rates, with more errors being made for incongruent trials ( $Z = 91.00, p = .001, r = .70$ ) and between incongruent and neutral

(*Median* = 0.00, *range* = 0.00-1.00) trials, with more errors being made for incongruent trials ( $Z = 11.00$ ,  $p = .01$ ,  $r = .58$ ). The difference between congruent and neutral error rates wasn't significant ( $Z = 6.00$ ,  $p = .08$ ,  $r = .37$ ). Therefore, incongruency of font colour and word caused more errors and longer breakthrough RTs showing that the font colour and word bound preconsciously.

## 5.6 Discussion

This study aimed to investigate the extent to which subliminally viewed graphemes bind with their concurrent colour. The first set of experiments assessed whether a digit presented using GCC would prime RTs or error rates. We showed that the priming digit influenced error rates for identification of subsequent target graphemes, with more errors being made for repetition incongruent compared to congruent trials (Experiment 1A). However, when the target was a colour patch there was no difference in error rates between congruent and incongruent trials for the GC synaesthetes (Experiment 1B). This suggests that the digits didn't bind with their concurrent colours. For those synaesthetes who experienced colours during the digit detection task, this didn't improve accuracy even though it improved response confidence (Experiment 1C). Furthermore, when a colour was experienced for the peripherally presented digit, it was likely to match the digit that they reported having seen during that trial, rather than the digit that was actually presented. Overall, there was no evidence of grapheme and colour binding for the GCC presented digits.

Next, we asked whether a grapheme displayed unconsciously using CFS would influence the time it took to break through into conscious awareness. When comparing detection of graphemes with a colourful or greyscale concurrent (Experiment 2A), or when comparing graphemes presented in their congruent or incongruent colour (Experiment 2B), no differences in time to breakthrough or error rates were evident.

Finally, we showed colour words presented in the congruent font colour broke through into conscious awareness faster and had fewer errors than colour words with incongruent font colour (Experiment 2C). This is the first time a classic Stroop task has been conducted using CFS. Together, these results show that although the CFS stimuli could be processed enough to influence break through time for colour words, there was no evidence of grapheme and colour binding occurring under CFS for the GC synaesthetes.

These findings support previous studies of GC synaesthesia and consciousness as there was no behavioural evidence in the form of accuracy or RTs to indicate the grapheme binds with its concurrent colour when it is viewed without conscious awareness (Mattingley et al., 2001; Rich & Mattingley, 2010). As the graphemes in the GCC experiments were viewed peripherally with the participant asked to focus on the central fixation cross, this also supports research showing that attention is required for the grapheme and colour to bind (Rich & Mattingley, 2010; Sagiv et al., 2006). In the CFS studies participants viewed the grapheme in foveal vision but without conscious awareness and still the grapheme and colour didn't bind, providing additional support that conscious awareness is required for synaesthetic binding. Unlike previous studies, the stimuli in this series of experiments were displayed for seconds, much longer than the milliseconds durations of the masking tasks. This allowed extra stimulus viewing time for possible triggering of the concurrent colour, and binding of the colour with the grapheme. Insufficient stimulus exposure therefore can't account for the lack of behavioural influence from grapheme manipulations.

Colours were experienced by some synaesthetes even when the priming digit was not detected, which supported previous peripheral crowding research (Ward et al., 2007). Even more surprisingly, some colours didn't match any of the digit choices for

that trial. Some synaesthetes spontaneously stated during the digit detection task that they were confused because the colour didn't match any of the digit choice options. Furthermore, they gave these colours even though it was stated very clearly to synaesthetes before the start of Experiment 1C that it didn't matter whether they experienced any colours or not, either way it was informative to us. This was to make sure synaesthetes didn't feel like they were failing at the task if they didn't experience colours for the GCC digits. This corresponds to research showing synaesthetic concurrents don't influence contrast and chromatic adaptation (processed by early visual mechanisms) (Hong & Blake, 2008). As early visual feature detection didn't trigger synaesthetic concurrents using either GCC or CFS but colours were experienced when no grapheme was detected this study supports the role of attention which has been found necessary for GC synaesthesia generation by a host of research (Mattingley et al., 2006; Mattingley, 2009; Sagiv, Heer, & Robertson, 2006; Ward et al., 2010). Furthermore, this suggests that synaesthetic colour can be internally generated without the need for an external inducing grapheme. The colour experiences for chosen digits (rather than the actually primed digits) in Experiment 1C were, however, negatively related to the associator measure of the R-RSPA and not correlated with the projector measure. Previous research of mentally generated graphemes has found inconsistent priming results suggesting variability between the phenomenology and behaviour relationship of GC synaesthetes when imagining graphemes (Spiller & Jansari, 2008). More investigation of how colours are triggered without processing of an external stimulus may explain what mechanism underlie internally generated synaesthetic colour experience.

Dimensions of the CLaN correlated with behavioural measures in Experiments 1A and 1B. Automaticity and attention correlated negatively with error rates; therefore,

greater errors were associated with synaesthetes who experienced lower levels of automaticity and increased attentional requirements for the creation of their synaesthetic concurrent. However, greater error rates, lower levels of automaticity, and increased attentional requirements may all be due to individual differences in general attentiveness rather than in synaesthetic phenomenology. Longitudinal change correlated negatively with RTs; therefore, longer RTs were associated with synaesthetes who have experienced little change in the strength of their colour concurrents (either becoming stronger or weaker) over time. The relationship between projector and associator dimensions was less clear, with generally low correlations against behavioural measures. Considering that colour locus has been linked to behaviour differences in Stroop tasks previously (Dixon et al., 2004) it is unclear why this relationship is not consistent. Furthermore, it suggests that colour locus should not be the primary synaesthete grouping strategy when studying variability within GC synaesthetes. This demonstrates the need to explore phenomenology more fully when contrasting GC synaesthesia sub-groups.

The lack of benefit for consciously detecting the grapheme when it was coloured compared to black whilst under CFS for control participants (Experiment 2A) showed that the colour didn't aid breakthrough. As colour breaks through more readily than other visual properties (Hong & Blake, 2009) it was predicted that the coloured graphemes would be detected faster. Our task however was to name the grapheme, not the colour. Although colour isn't subject to suppression as fully as other visual properties of a static visual stimulus, the colour isn't fixed (Hong & Blake, 2009), so the colour may have been perceived before the grapheme had been detected and reported. This finding shouldn't however impact on the synaesthete findings, as we did find faster break through in the Stroop study (Experiment 2C) for congruent trials.

Although graphemes didn't bind with their concurrent colour under CFS, the colour words did. This shows that semantic information is accessible despite suppression, supporting previous research of semantic processing under CFS (Costello, Jiang, Baartman, McGlennen, & He, 2009; Yang & Yeh, 2011). This also supports a variety of research paradigms that have shown congruency of suppressed stimuli influences breakthrough time (Alsius & Munhall, 2013; Salomon & Lim, 2013; Zhou, Jiang, He, & Chen, 2010; for a review see Gayet, Van der Stigchel, & Paffen, 2014).

The Stroop CFS paradigm could be used to test preconscious binding of colour words and colours for synaesthetes with alien colour effect, where the colours experienced by colour words are not the actual colours they refer to (Gray et al., 2006). If RTs and error rates are similar to those of controls, then it would support the current study, showing that the colour word and associated colour don't bind without conscious awareness for synaesthetes. If interference is measured in relation to their synaesthetic concurrent rather than the font colour, then pre conscious word and colour binding would be evident.

The detection of images in Experiment 1C was not at chance levels. This suggests that in some trials, participants may have been aware of what digit was being presented in the periphery. Although this doesn't detract from the tendency for colours experienced by synaesthetes to match the digit they thought they saw, rather than the one actually presented, the conscious detection of graphemes could be controlled more rigidly by using a staircase design. By measuring the minimum size of digit which can be consciously seen within the crowding and setting the test stimulus to just below this, the conscious detection of digits could be reduced to chance levels.

Overall, this study showed that even with long viewing times, subliminally viewed graphemes don't bind with their concurrent colours for GC synaesthetes. Even so, colours were still experienced and critically often didn't match their concurrent for the primed grapheme, suggesting a strong role of top-down systems for the generation of the colour.

## **FINAL CONCLUSIONS OF THE THESIS**

This thesis sought to investigate the links between conscious phenomenology and behavioural advantages associated in synaesthesia. This was completed from two complementary approaches. First, hypnosis was used to create synaesthesia-like phenomenology in high susceptible participants. From Chapters 2 and 3 it was shown that the phenomenology of synaesthesia is not restricted to synaesthetes, high susceptible participants can have similar conscious experiences of percepts linked to particular concurrents. Chapter 2 showed that GC synaesthesia experiences could be evoked, although the suggestion did not work for all participants. The reported vividness and disparity of colour experienced was however remarkably similar to that of developmental synaesthetes. Chapter 3 showed that an MS synaesthesia-like experience could be triggered however the experience of sound was not confined to the high susceptible participants, people also experienced it from mental imagery instruction. Furthermore, many participants heard beeps without any instruction in the baseline measure, suggesting that non-MS synaesthetes deliberately pair visual flashes and beeps as a task strategy. Together, this shows that the phenomenology of synaesthesia is not restricted to developmental synaesthetes (although the pairing of beeps and visual images in non-MS synaesthetes may be a deliberate strategy, rather than an automatic association). In Chapter 2, more vivid colours and a greater degree of digits appeared as

coloured in accurate trials where the shape had been identified within the array. This was suggested to be due to the ability to use mental imagery more efficiently. Once the shape has been identified it is easier to then mentally project the colours onto the digit array. This supports previous literature suggesting a link between synaesthesia and mental imagery (Barnett & Newell, 2008; Price, 2009; Spiller & Jansari, 2008; Spiller et al., 2015).

In Chapters 2 and 3, I also investigated whether hypnotic synaesthesia causes behavioural advantages similar to developmental synaesthetes. The phenomenology of synaesthesia wasn't associated with task improvement. This supports theories of hypnosis that propose that hypnosis can't create any new special abilities in participants that they could not achieve without the use of hypnosis, such as the cold control theory (Dienes & Perner, 2007). However, the lack of behavioural improvement may be due to the practice that developmental synaesthetes have of experiencing the synaesthetic concurrent. Synaesthetes may be more practiced in integrating the grapheme and concurrent colour features (Sagiv & Robertson, 2005). Conscious visual experience, rather than being a direct representation of the external world, has suggested to be more of an active exploration of the world mediated by a set of rules based on how the being moves within the world (O'Regan & Noë, 2001). These rules (sensorimotor contingencies) are different depending on the sensory modality, for example the rules for vision would be different for those of audition, and practice is required to master understanding of these rules. This change towards viewing cognition as action (Engel, Maye, Kurthen, & König, 2013) could therefore account for the lack of behavioural improvement in the hypnotic synaesthetes in Chapters 2 and 3. Training synaesthesia studies have shown that changes in behaviour after training participants to link grapheme with colours which are similar to developmental synaesthetes (Bor, Rothen,



Schwartzman, Clayton, & Seth, 2014). As practice was required for the behavioural changes in the trained synaesthetes, and ‘cognition is action’ (O’Regan & Noë, 2001), this may account for the lack of behavioural advantage associated with the synaesthetic phenomenology seen in Chapters 2 and 3. This is because the hypnotic synaesthetes have not had practice in actively mastering their understanding of the synaesthetic concurrent.

In Chapter 4 the individual differences of GC phenomenology were researched by completing principle component analysis (PCA) of two existing questionnaires designed to categorise synaesthetes as either a projector or associator (Rouw & Scholte, 2007; Skelton et al., 2009). After PCA two revised questionnaires were made, the R-RSPA and R-ISEQ. As both these questionnaires had two factors corresponding to projector and associator, it was determined that these are separate dimensions of synaesthetic experience and should be treated as such in research.

In Chapter 5 I researched whether a synaesthete has to be consciously aware of a grapheme for it to bind with its concurrent colour. Developmental GC synaesthetes completed detection tasks for graphemes which were presented subliminally. Their performance showed that graphemes don’t bind with their associated concurrent pre-consciously supporting previous literature (Mattingley et al., 2001; Sagiv et al., 2006). By presenting the graphemes (via CFS) for a long time in comparison to previous literature, I was able to show that it wasn’t short stimulus presentation times which accounts for the lack of grapheme-colour binding as measured using objective behavioural measures of accuracy and RT. I also supported the finding that even without conscious awareness of a grapheme, a synaesthete can still have a colour experience although this colour doesn’t necessarily match the concurrent colour for the presented grapheme (Ward et al., 2007). Therefore phenomenology of synaesthesia is

not limited to the perception of externally generated graphemes, they can also be internally generated. This further supports the link between mental imagery and synaesthesia (Simner, 2013) which was also evident in Chapter 2 although not this relationship was not as clear in Chapter 3.

Finally, throughout this thesis large individual variations were measured. This was evident in the degree to which high susceptible participants experienced the grapheme-colour synaesthesia suggestion when viewing graphemes in Chapter 2. In Chapter 3 there was variability not only in the level that participants experienced the mental imagery or hypnotic hearing-motion suggestion, but also whether this was a spontaneous strategy they used at baseline varied. In Chapter 4 I showed that even the division of GC synaesthetes as projector or associator is not clear cut, with some synaesthetes having both types of experience in response to graphemes. Furthermore, in Chapter 5 there was large variation in the number of colours which GC synaesthetes experienced to subliminally presented graphemes and whether these matched the concurrent for the grapheme presented. Individual differences are therefore a very important aspect of both synaesthesia and hypnosis research.

## **References**

- Acosta Jr, E., & Crawford, H. J. (1985). Iconic Memory and Hypnotizability : Processing Speed , Skill , or Strategy Differences ? *International Journal of Clinical and Experimental Hypnosis*, 33(3), 236–245.
- Ahmias, C. L. N. (1998). Where the imaginal appears real : A positron emission tomography, 95(February), 1956–1960.
- Alsius, A., & Munhall, K. G. (2013). Detection of audiovisual speech correspondences without visual awareness. *Psychological Science*, 24(4), 423–31. doi:10.1177/0956797612457378
- Anderson, H. P., Seth, A. K., Dienes, Z., & Ward, J. (2014). Can grapheme-color synesthesia be induced by hypnosis? *Frontiers in Human Neuroscience*, 8(April), 220. doi:10.3389/fnhum.2014.00220
- Armel, K., & Ramachandran, V. (1999). Acquired synesthesia in retinitis pigmentosa. *Neurocase*, 5, 293–296.
- Auvray, M., & Farina, M. (n.d.). Patrolling the boundaries of synaesthesia: a critical appraisal of transient and artificially-acquired forms of synaesthetic experiences. In *Sensory Blendings: New essays on synaesthesia*.
- Banissy, M. J., Cohen Kadosh, R., Maus, G. W., Walsh, V., & Ward, J. (2009). Prevalence, characteristics and a neurocognitive model of mirror-touch synaesthesia. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale*, 198(2-3), 261–72. doi:10.1007/s00221-009-1810-9
- Banissy, M. J., & Ward, J. (2007). Mirror-touch synesthesia is linked with empathy. *Nature Neuroscience*, 10(7), 815–6. doi:10.1038/nn1926
- Bargary, G., & Mitchell, K. J. (2008). Synaesthesia and cortical connectivity. *Trends in Neurosciences*, 31(7), 335–42. doi:10.1016/j.tins.2008.03.007
- Barnes, S. M., Lynn, S. J., & Pekala, R. J. (2009). Not all group hypnotic suggestibility scales are created equal: individual differences in behavioral and subjective responses. *Consciousness and Cognition*, 18(1), 255–65. doi:10.1016/j.concog.2008.07.006
- Barnett, K. J., Finucane, C., Asher, J. E., Bargary, G., Corvin, A. P., Newell, F. N., & Mitchell, K. J. (2008). Familial patterns and the origins of individual differences in synaesthesia. *Cognition*, 106(2), 871–93. doi:10.1016/j.cognition.2007.05.003
- Barnett, K. J., Foxe, J. J., Molholm, S., Kelly, S. P., Shalgi, S., Mitchell, K. J., & Newell, F. N. (2008). Differences in early sensory-perceptual processing in synesthesia: a visual evoked potential study. *NeuroImage*, 43(3), 605–13. doi:10.1016/j.neuroimage.2008.07.028

- Barnett, K. J., & Newell, F. N. (2008). Synaesthesia is associated with enhanced, self-rated visual imagery. *Consciousness and Cognition*, 17(3), 1032–9. doi:10.1016/j.concog.2007.05.011
- Baron-Cohen, S. (1996). Is there a normal phase of synaesthesia in development. *Psyche*, 2(27).
- Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton, P. (1996). Synaesthesia: prevalence and familiarity. *Perception*, 25(9), 1073–1079.
- Baron-Cohen, S., Harrison, J., Goldstein, L. H., & Wyke, M. (1993). Coloured speech perception: is synaesthesia what happens when modularity breaks down? *Perception*, 22(4), 419–426. doi:10.1068/p220419
- Blajenkova, O., Kozhevnikov, M., & Motes, M. a. (2006). Object-spatial imagery: A new self-report imagery questionnaire. *Applied Cognitive Psychology*, 20(2), 239–263. doi:10.1002/acp.1182
- Blake, R., Palmeri, T., Marois, R., & Chai-Youn, K. (2005). On the perceptual reality of synesthetic color. In L. C. Robertson & N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience* (pp. 47–73). New York, NY, US: New York, NY, US: Oxford University Press.
- Bor, D., Rothen, N., Schwartzman, D. J., Clayton, S., & Seth, A. K. (2014). Adults Can Be Trained to Acquire Synesthetic Experiences. *Scientific Reports*, 4, 7089. doi:10.1038/srep07089
- Bowers, K. S. (1998). Waterloo-stanford group scale of hypnotic susceptibility , form c : Manual and response booklet. *International Journal of Clinical and Experimental Hypnosis*, 46(3), 250–268.
- Brang, D., Rouw, R., Ramachandran, V. S., & Coulson, S. (2011). Similarly shaped letters evoke similar colors in grapheme-color synesthesia. *Neuropsychologia*, 49(5), 1355–8. doi:10.1016/j.neuropsychologia.2011.01.002
- Brochard, R., Dufour, A., & Després, O. (2004). Effect of musical expertise on visuospatial abilities: evidence from reaction times and mental imagery. *Brain and Cognition*, 54(2), 103–9. doi:10.1016/S0278-2626(03)00264-1
- Brown, R., & Oakley, D. (2004, October 15). An integrative cognitive theory of hypnosis and high hypnotizability. Brunner-Routledge.
- Coe, W. C., St Jean, R. L., & Burger, J. M. (1980). Hypnosis and the enhancement of visual imagery. *The International Journal of Clinical and Experimental Hypnosis*, 28(3), 225–43. doi:10.1080/00207148008409848
- Cohen Kadosh, R., Henik, A., Catena, A., Walsh, V., & Fuentes, L. J. (2009). Induced cross-modal synaesthetic experience without abnormal neuronal connections. *Psychological Science*, 20(2), 258–65. doi:10.1111/j.1467-9280.2009.02286.x

- Cohen Kadosh, R., Henik, A., & Walsh, V. (2009). Synaesthesia: learned or lost? *Developmental Science*, 12(3), 484–91. doi:10.1111/j.1467-7687.2008.00798.x
- Cohen Kadosh, R., Sagiv, N., Linden, D. E. J., Robertson, L. C., Elinger, G., & Henik, A. (2005). When blue is larger than red: colors influence numerical cognition in synesthesia. *Journal of Cognitive Neuroscience*, 17(11), 1766–73. doi:10.1162/089892905774589181
- Costello, P., Jiang, Y., Baartman, B., McGlennen, K., & He, S. (2009). Semantic and subword priming during binocular suppression. *Consciousness and Cognition*, 18(2), 375–82. doi:10.1016/j.concog.2009.02.003
- Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: a proposal. *Trends in Cognitive Sciences*, 9(7), 335–41. doi:10.1016/j.tics.2005.05.004
- Deroy, O., & Spence, C. (2013). Training, hypnosis, and drugs: artificial synaesthesia, or artificial paradises? *Frontiers in Psychology*, 4(October), 660. doi:10.3389/fpsyg.2013.00660
- Dienes, Z. (2011). Bayesian Versus Orthodox Statistics: Which Side Are You On? *Perspectives on Psychological Science*, 6(3), 274–290. doi:10.1177/1745691611406920
- Dienes, Z., Brown, E., Hutton, S., Kirsch, I., Mazzoni, G., & Wright, D. B. (2009). Hypnotic suggestibility, cognitive inhibition, and dissociation. *Consciousness and Cognition*, 18(4), 837–47. doi:10.1016/j.concog.2009.07.009
- Dienes, Z., & Perner, J. (2007). Executive control without conscious awareness: the cold control theory. *Hypnosis and Conscious States: The ...*, 293–314.
- Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: projector versus associator synaesthetes. *Cognitive, Affective & Behavioral Neuroscience*, 4(3), 335–43.
- Eagleman, D. M., & Goodale, M. a. (2009). Why color synesthesia involves more than color. *Trends in Cognitive Sciences*, 13(7), 288–92. doi:10.1016/j.tics.2009.03.009
- Eagleman, D. M., Kagan, A. D., Nelson, S. S., Sagaram, D., & Sarma, A. K. (2007). A standardized test battery for the study of synesthesia. *Journal of Neuroscience Methods*, 159(1), 139–45. doi:10.1016/j.jneumeth.2006.07.012
- Edquist, J., Rich, A. N., Brinkman, C., & Mattingley, J. B. (2006). Do synaesthetic colours act as unique features in visual search? *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 42(2), 222–31.
- Egner, T., Jamieson, G., & Gruzelier, J. (2005). Hypnosis decouples cognitive control from conflict monitoring processes of the frontal lobe. *NeuroImage*, 27(4), 969–78. doi:10.1016/j.neuroimage.2005.05.002

- Engel, A. K., Maye, A., Kurthen, M., & König, P. (2013). Where's the action? The pragmatic turn in cognitive science. *Trends in Cognitive Sciences*, 17(5), 202–209. doi:10.1016/j.tics.2013.03.006
- Faivre, N., Berthet, V., & Kouider, S. (2012). Nonconscious influences from emotional faces: a comparison of visual crowding, masking, and continuous flash suppression. *Frontiers in Psychology*, 3(May), 129. doi:10.3389/fpsyg.2012.00129
- Farvolden, P., & Woody, E. Z. (2004). Hypnosis, memory, and frontal executive functioning. *The International Journal of Clinical and Experimental Hypnosis*, 52(1), 3–26. doi:10.1076/iceh.52.1.3.23926
- Freeman, R., Barabasz, A., Barabasz, M., & Warner, D. (2000). Hypnosis and Distraction Differ in Their Effects on Cold Pressor Pain. *American Journal of Clinical Hypnosis*, 43(2), 137–148. doi:10.1080/00029157.2000.10404266
- Friedman, H., Taub, H., Sturr, J. F., & Monty, R. A. (1987). Visual information processing speed in hypnotized and nonhypnotized subjects. *The Journal of General ...*, 114(4), 363–372.
- Gandhi, B., & Oakley, D. a. (2005). Does “hypnosis” by any other name smell as sweet? The efficacy of “hypnotic” inductions depends on the label “hypnosis”. *Consciousness and Cognition*, 14(2), 304–15. doi:10.1016/j.concog.2004.12.004
- Gayet, S., Van der Stigchel, S., & Paffen, C. L. E. (2014). Breaking continuous flash suppression: competing for consciousness on the pre-semantic battlefield. *Frontiers in Psychology*, 5(May), 460. doi:10.3389/fpsyg.2014.00460
- Gebuis, T., Nijboer, T. C. W., & Van der Smagt, M. J. (2009). Multiple dimensions in bi-directional synesthesia. *The European Journal of Neuroscience*, 29(8), 1703–10. doi:10.1111/j.1460-9568.2009.06699.x
- Gheri, C., & Baldassi, S. (2008). Non-linear integration of crowded orientation signals. *Vision Research*, 48(22), 2352–8. doi:10.1016/j.visres.2008.07.022
- Glenberg, a M., Mann, S., Altman, L., Forman, T., & Procise, S. (1989). Modality effects in the coding and reproduction of rhythms. *Memory & Cognition*, 17(4), 373–83.
- Glisky, M. L., Tatarzyn, D. J., & Kihlstrom, J. F. (1995). Hypnotizability and mental imagery. *The International Journal of Clinical and Experimental Hypnosis*, 43(1), 34–54. doi:10.1080/00207149508409374
- Gray, J. A., Parslow, D. M., Brammer, M. J., Chopping, S., Vythelingum, G. N., & Dominic, H. (2006). Evidence against functionalism from neuroimaging of the alien colour effect in synaesthesia. *Cortex*, 42, 309–318.
- Grossenbacher, P. G., & Lovelace, C. T. (2001). Mechanisms of synesthesia: cognitive and physiological constraints. *Trends in Cognitive Sciences*, 5(1), 36–41.

- Gruzelier, J. H. (2006). Frontal functions, connectivity and neural efficiency underpinning hypnosis and hypnotic susceptibility. *Contemporary Hypnosis*, 23(1), 15–32. doi:10.1002/ch
- Guttman, S. E., Gilroy, L. a, & Blake, R. (2005). Hearing what the eyes see: auditory encoding of visual temporal sequences. *Psychological Science*, 16(3), 228–35. doi:10.1111/j.0956-7976.2005.00808.x
- Hasegawa, H., & Jamieson, G. (2002). Conceptual issues in hypnosis research: explanations, definitions and the state/non-state debate. *Contemporary Hypnosis*, 19(3), 103–118.
- Hilgard, E. R. (1986). *Divided Consciousness: Multiple Controls in Human Thought and Action*. New York: Wiley.
- Holmes, E. a, Brown, R. J., Mansell, W., Fearon, R. P., Hunter, E. C. M., Frasquilho, F., & Oakley, D. a. (2005). Are there two qualitatively distinct forms of dissociation? A review and some clinical implications. *Clinical Psychology Review*, 25(1), 1–23. doi:10.1016/j.cpr.2004.08.006
- Hong, S., & Blake, R. (2009). Interocular suppression differentially affects achromatic and chromatic mechanisms. *Attention, Perception, & Psychophysics*, 71(2), 403–411. doi:10.3758/APP
- Hong, S. W., & Blake, R. (2008). Early visual mechanisms do not contribute to synesthetic color experience. *Vision Research*, 48(8), 1018–26. doi:10.1016/j.visres.2008.01.024
- Horton, J. E., Crawford, H. J., Harrington, G., & Downs, J. H. (2004). Increased anterior corpus callosum size associated positively with hypnotizability and the ability to control pain. *Brain : A Journal of Neurology*, 127(Pt 8), 1741–7. doi:10.1093/brain/awh196
- Hubbard, E. M., Arman, a C., Ramachandran, V. S., & Boynton, G. M. (2005). Individual differences among grapheme-color synesthetes: brain-behavior correlations. *Neuron*, 45(6), 975–85. doi:10.1016/j.neuron.2005.02.008
- Hubbard, E. M., Brang, D., & Ramachandran, V. S. (2011). The cross-activation theory at 10. *Journal of Neuropsychology*, 5(2), 152–77. doi:10.1111/j.1748-6653.2011.02014.x
- Hubbard, E. M., Manohar, S., & Ramachandran, V. S. (2006). Contrast affects the strength of synesthetic colors. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 42(2), 184–94.
- Hubbard, E. M., & Ramachandran, V. S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron*, 48(3), 509–20. doi:10.1016/j.neuron.2005.10.012
- Hubbard, E., & Ramachandran, V. (2003). The phenomenology of synaesthesia. *Journal of Consciousness Studies*, 10(8), 49–57.

- Jiang, Y., Costello, P., & He, S. (2007). Processing of invisible stimuli: Advantage of upright faces and recognizable words in overcoming interocular suppression. *Psychological Science*, 18(4), 349–355.
- Kass, R., & Raftery, A. (1995). Bayes factors. *Journal of the American Statistical ...*, 90(430), 773–795.
- Kihlstrom, J. F. (2013). Neuro-hypnotism: Prospects for hypnosis and neuroscience. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 49(2), 365–74. doi:10.1016/j.cortex.2012.05.016
- Kim, C., Blake, R., & Palmeri, T. (2006). Perceptual interaction between real and synesthetic colors. *Cortex*, 42(2), 195–203.
- Kirsch, I. (1985). Response expectancy as a determinant of experience and behavior. *American Psychologist*, 1189–1202.
- Kirsch, I. (2011). The altered state issue: dead or alive? *The International Journal of Clinical and Experimental Hypnosis*, 59(3), 350–62. doi:10.1080/00207144.2011.570681
- Kooi, F., Toet, A., Tripathy, S., & Levi, D. (1994). The effect of similarity and duration on spatial interaction in peripheral vision. *Spatial Vision*, 8(2), 255–279.
- Kosslyn, S. M., Behrmann, M., & Jeannerod, M. (1995). The cognitive neuroscience of mental imagery. *Neuropsychologia*, 33(11), 1335–1344.
- Kosslyn, S. M., Thompson, W. L., Costantini-ferrando, M. F., & Spiegel, D. (2000). Hypnotic Visual Illusion Alters Color Processing in the Brain. *American Journal of Psychiatry*, 157(August), 1279–1284.
- Kouider, S., Berthet, V., & Faivre, N. (2011). Preference is biased by crowded facial expressions. *Psychological Science*, 22(2), 184–9. doi:10.1177/0956797610396226
- Laeng, B., Svarddal, F., & Oelmann, H. (2004). Does color synesthesia pose a paradox for early-selection theories of attention? *Psychological Science*, 15(4), 277–81. doi:10.1111/j.0956-7976.2004.00666.x
- Lau, H., & Rosenthal, D. (2011). Empirical support for higher-order theories of conscious awareness. *Trends in Cognitive Sciences*, 15(8), 365–73. doi:10.1016/j.tics.2011.05.009
- Lifshitz, M., Cusumano, E. P., & Raz, A. (2013). Hypnosis as neurophenomenology. *Frontiers in Human Neuroscience*, 7(August), 469. doi:10.3389/fnhum.2013.00469
- Lin, Z., & He, S. (2009). Seeing the invisible: the scope and limits of unconscious processing in binocular rivalry. *Progress in Neurobiology*, 87(4), 195–211. doi:10.1016/j.pneurobio.2008.09.002.Seeing



- Luke, D., Friday, R., & Terhune, D. (2012). Psychedelic synaesthesia: Evidence for a serotonergic role in synaesthesia. *Seeing and Perceiving*, 25, 74–74. doi:10.1163/187847612X646956
- Luke, D. P., & Terhune, D. B. (2013). The induction of synaesthesia with chemical agents: a systematic review. *Frontiers in Psychology*, 4(October), 1–12. doi:10.3389/fpsyg.2013.00753
- Lynn, S. J., & Green, J. P. (2011). The sociocognitive and dissociation theories of hypnosis: toward a rapprochement. *The International Journal of Clinical and Experimental Hypnosis*, 59(3), 277–93. doi:10.1080/00207144.2011.570652
- Maquet, P., Faymonville, M., & Degueldre, C. (1999). Functional neuroanatomy of hypnotic state. *Biological ...*, 45(3), 327–333.
- Marks, B. Y. D. F., & Marks, F. (1973). Visual imagery differences in the recall of pictures. *British Journal of Psychology*, 64(1), 17–24.
- Mattingley, J. B. (2009). Attention, automaticity, and awareness in synesthesia. *Annals of the New York Academy of Sciences*, 1156, 141–67. doi:10.1111/j.1749-6632.2009.04422.x
- Mattingley, J. B., Payne, J. M., & Rich, A. N. (2006). Attentional load attenuates synaesthetic priming effects in grapheme-colour synaesthesia. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 42(2), 213–21.
- Mattingley, J. B., Rich, a N., Yelland, G., & Bradshaw, J. L. (2001). Unconscious priming eliminates automatic binding of colour and alphanumeric form in synaesthesia. *Nature*, 410(6828), 580–2. doi:10.1038/35069062
- Mazzoni, G., Rotriquenz, E., Carvalho, C., Vannucci, M., Roberts, K., & Kirsch, I. (2009). Suggested visual hallucinations in and out of hypnosis. *Consciousness and Cognition*, 18(2), 494–9. doi:10.1016/j.concog.2009.02.002
- McGeown, W. J., Venneri, A., Kirsch, I., Nocetti, L., Roberts, K., Foan, L., & Mazzoni, G. (2012). Suggested visual hallucination without hypnosis enhances activity in visual areas of the brain. *Consciousness and Cognition*, 21(1), 100–16. doi:10.1016/j.concog.2011.10.015
- Meier, B., & Rothen, N. (2009). Training grapheme-colour associations produces a synaesthetic Stroop effect, but not a conditioned synaesthetic response. *Neuropsychologia*, 47(4), 1208–1211. doi:10.1016/j.neuropsychologia.2009.01.009
- Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*. doi:10.1111/1467-9280.00474
- Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, 80(3), 215–29.

- Naish, P. L. N. (2010). Hypnosis and hemispheric asymmetry. *Consciousness and Cognition*, 19(1), 230–4. doi:10.1016/j.concog.2009.10.003
- Nikolić, D., Lichti, P., & Singer, W. (2007). Color opponency in synaesthetic experiences. *Psychological Science*, 18(6), 481–6. doi:10.1111/j.1467-9280.2007.01925.x
- Nordenstrom, B. K., Council, J. R., & Meier, B. P. (2002). The “big five” and hypnotic suggestibility. *The International Journal of Clinical and Experimental Hypnosis*, 50(3), 276–81. doi:10.1080/00207140208410103
- O'Regan, J. K., & Noë, a. (2001). A sensorimotor account of vision and visual consciousness. *The Behavioral and Brain Sciences*, 24(5), 939–973; discussion 973–1031. doi:10.1017/S0140525X01000115
- Oakley, D. a, & Halligan, P. W. (2013). Hypnotic suggestion: opportunities for cognitive neuroscience. *Nature Reviews. Neuroscience*, 14(8), 565–76. doi:10.1038/nrn3538
- Oakley, D. A., & Halligan, P. W. (2009). Hypnotic suggestion and cognitive neuroscience. *Trends in Cognitive Sciences*, 13(6), 264–70. doi:10.1016/j.tics.2009.03.004
- Palmeri, T. J., Blake, R., Marois, R., Flanery, M. a, & Whetsell, W. (2002). The perceptual reality of synesthetic colors. *Proceedings of the National Academy of Sciences of the United States of America*, 99(6), 4127–31. doi:10.1073/pnas.022049399
- Piccione, C., Hilgard, E. R., & Zimbardo, P. G. (1989). On the degree of stability of measured hypnotizability over a 25-year period. *Journal of Personality and Social Psychology*, 56(2), 289–95.
- Price, M. C. (2009). Spatial forms and mental imagery. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 45(10), 1229–45. doi:10.1016/j.cortex.2009.06.013
- Rainville, P., Hofbauer, R. K., Bushnell, M. C., Duncan, G. H., & Price, D. D. (2002). Hypnosis modulates activity in brain structures involved in the regulation of consciousness. *Journal of Cognitive Neuroscience*, 14(6), 887–901. doi:10.1162/089892902760191117
- Ramachandran, V., & Hubbard, E. (2001). Synaesthesia--a window into perception, thought and language. *Journal of Consciousness ...*, (12), 3–34.
- Ramachandran, V. S., & Hubbard, E. M. (2001). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings. Biological Sciences / The Royal Society*, 268(1470), 979–83. doi:10.1098/rspb.2000.1576

- Raz, A., Kirsch, I., Pollard, J., & Nitkin-Kaner, Y. (2006). Suggestion reduces the stroop effect. *Psychological Science*, 17(2), 91–5. doi:10.1111/j.1467-9280.2006.01669.x
- Raz, A., Landzberg, K. S., Schweizer, H. R., Zephrani, Z. R., Shapiro, T., Fan, J., & Posner, M. I. (2003). Posthypnotic suggestion and the modulation of Stroop interference under cycloplegia. *Consciousness and Cognition*, 12(3), 332–346. doi:10.1016/S1053-8100(03)00024-2
- Raz, A., Moreno-Iñiguez, M., Martin, L., & Zhu, H. (2007). Suggestion overrides the Stroop effect in highly hypnotizable individuals. *Consciousness and Cognition*, 16(2), 331–8. doi:10.1016/j.concog.2006.04.004
- Raz, A., & Shapiro, T. (2002). Hypnosis and Neuroscience. *Archives of General Psychiatry*, 59(1), 85. doi:10.1001/archpsyc.59.1.85
- Raz, A., Shapiro, T., Fan, J., & Posner, M. I. (2002). Hypnotic suggestion and the modulation of Stroop interference. *Archives of General Psychiatry*, 59(12), 1155–61.
- Reisberg, D., Pearson, D. G., & Kosslyn, S. M. (2003). Intuitions and introspections about imagery: The role of imagery experience in shaping an investigator's theoretical views. *Applied Cognitive Psychology*, 17(2), 147–160. doi:10.1002/acp.858
- Reynvoet, B., & Ratinckx, E. (2004). Hemispheric differences between left and right number representations: effects of conscious and unconscious priming. *Neuropsychologia*, 42(6), 713–26. doi:10.1016/j.neuropsychologia.2003.11.013
- Rhue, J. W., & Lynn, S. J. (1989). Fantasy proneness, hypnotizability, and absorption--a re-examination: a brief communication. *The International Journal of Clinical and Experimental Hypnosis*, 37(2), 100–6. doi:10.1080/00207148908410539
- Rich, A. N., & Mattingley, J. B. (2010). Out of sight, out of mind: the attentional blink can eliminate synaesthetic colours. *Cognition*, 114(3), 320–8. doi:10.1016/j.cognition.2009.10.003
- Rich, A. N., Williams, M. a, Puce, A., Syngienotis, A., Howard, M. a, McGlone, F., & Mattingley, J. B. (2006). Neural correlates of imagined and synaesthetic colours. *Neuropsychologia*, 44(14), 2918–25. doi:10.1016/j.neuropsychologia.2006.06.024
- Ro, T., Farnè, A., Johnson, R. M., Wedeen, V., Chu, Z., Wang, Z. J., ... Beauchamp, M. S. (2007). Feeling sounds after a thalamic lesion. *Annals of Neurology*, 62(5), 433–41. doi:10.1002/ana.21219
- Roberts, R., Callow, N., Hardy, L., Markland, D., & Bringer, J. (2008). Movement imagery ability: development and assessment of a revised version of the vividness of movement imagery questionnaire. *Journal of Sport & Exercise Psychology*, 30(2), 200–221.

- Rothen, N., & Meier, B. (2009). Do synesthetes have a general advantage in visual search and episodic memory? A case for group studies. *PloS One*, 4(4), e5037. doi:10.1371/journal.pone.0005037
- Rothen, N., Meier, B., & Ward, J. (2012). Enhanced memory ability: Insights from synaesthesia. *Neuroscience and Biobehavioral Reviews*, 36(8), 1952–63. doi:10.1016/j.neubiorev.2012.05.004
- Rothen, N., Nikolić, D., Jürgens, U. M., Mroczko-Wąsowicz, A., Cock, J., & Meier, B. (2013). Psychophysiological evidence for the genuineness of swimming-style colour synaesthesia. *Consciousness and Cognition*, 22(1), 35–46. doi:10.1016/j.concog.2012.11.005
- Rothen, N., Seth, A. K., Witzel, C., & Ward, J. (2013). Diagnosing synaesthesia with online colour pickers: maximising sensitivity and specificity. *Journal of Neuroscience Methods*, 215(1), 156–60. doi:10.1016/j.jneumeth.2013.02.009
- Rothen, N., Tsakanikos, E., Meier, B., & Ward, J. (2013). Coloured Letters and Numbers (CLaN): a reliable factor-analysis based synaesthesia questionnaire. *Consciousness and Cognition*, 22(3), 1047–60. doi:10.1016/j.concog.2013.07.005
- Rothen, N., Wantz, A.-L., & Meier, B. (2011). Training synaesthesia. *Perception*, 40(10), 1248–1250. doi:10.1068/p6984
- Rouw, R., & Scholte, H. S. (2007). Increased structural connectivity in grapheme-color synesthesia. *Nature Neuroscience*, 10(6), 792–7. doi:10.1038/nn1906
- Rouw, R., & Scholte, H. S. (2010). Neural basis of individual differences in synesthetic experiences. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, 30(18), 6205–13. doi:10.1523/JNEUROSCI.3444-09.2010
- Saenz, M., & Koch, C. (2008). The sound of change : visually- induced auditory synesthesia. *Current Biology : CB*, 18(15), 650–651.
- Sagiv, N., & Frith, C. D. (2013). Synesthesia and Consciousness. In J. Simner & E. M. Hubbard (Eds.), *The Oxford handbook of synesthesia* (pp. 924–940). Oxford: Oxford University Press. doi:10.1093/oxfordhb/9780199603329.013.0045
- Sagiv, N., Heer, J., & Robertson, L. (2006). Does binding of synesthetic color to the evoking grapheme require attention? *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 42(2), 232–42.
- Sagiv, N., & Robertson, L. C. (2005). Synesthesia and the binding problem. In *Synesthesia: Perspectives from Cognitive Neuroscience* (pp. 90–107).
- Salomon, R., & Lim, M. (2013). Posing for awareness : Proprioception modulates access to visual consciousness in a continuous flash suppression task, 13, 1–8. doi:10.1167/13.7.2.doi

- Simner, J. (2012). Defining synaesthesia. *British Journal of Psychology (London, England : 1953)*, 103(1), 1–15. doi:10.1348/000712610X528305
- Simner, J. (2013). Why are there different types of synesthete? *Frontiers in Psychology*, 4(SEP), 2–4. doi:10.3389/fpsyg.2013.00558
- Simner, J., Gärtner, O., & Taylor, M. D. (2011). Cross-modal personality attributions in synaesthetes and non-synaesthetes. *Journal of Neuropsychology*, 5(2), 283–301. doi:10.1111/j.1748-6653.2011.02009.x
- Simner, J., Harrold, J., Creed, H., Monroe, L., & Foulkes, L. (2009). Early detection of markers for synaesthesia in childhood populations. *Brain : A Journal of Neurology*, 132(Pt 1), 57–64. doi:10.1093/brain/awn292
- Simner, J., & Haywood, S. L. (2009). Tasty non-words and neighbours: the cognitive roots of lexical-gustatory synaesthesia. *Cognition*, 110(2), 171–81. doi:10.1016/j.cognition.2008.11.008
- Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S. A., Fraser, C., ... Ward, J. (2006). Synaesthesia: The prevalence of atypical cross-modal experiences. *Perception*, 35(8), 1024–1033. doi:10.1068/p5469
- Simner, J., Ward, J., Lanz, M., Jansari, A., Noonan, K., Glover, L., & Oakley, D. a. (2005). Non-random associations of graphemes to colours in synaesthetic and non-synaesthetic populations. *Cognitive Neuropsychology*, 22(8), 1069–85. doi:10.1080/02643290500200122
- Sinke, C., Halpern, J. H., Zedler, M., Neufeld, J., Emrich, H. M., & Passie, T. (2012). Genuine and drug-induced synesthesia: a comparison. *Consciousness and Cognition*, 21(3), 1419–34. doi:10.1016/j.concog.2012.03.009
- Skelton, R., Ludwig, C., & Mohr, C. (2009). A novel, illustrated questionnaire to distinguish projector and associator synaesthetes. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, 45(6), 721–9. doi:10.1016/j.cortex.2008.02.006
- Smilek, D., Dixon, M. J., Cudahy, C., & Merikle, P. M. (2001). Synaesthetic photisms influence visual perception. *Journal of Cognitive Neuroscience*, 13(7), 930–6. doi:10.1162/089892901753165845
- Spanos, N. P. (1986). Hypnotic behavior: A social-psychological interpretation of amnesia, analgesia, and “trance logic.” *Behavioral and Brain Sciences*, 9, 449–502. doi:10.1017/S0140525X00046537
- Spector, F., & Maurer, D. (2009). Synesthesia: a new approach to understanding the development of perception. *Developmental Psychology*, 45(1), 175–89. doi:10.1037/a0014171

- Spiller, M. J., & Jansari, A. S. (2008). Mental imagery and synaesthesia: Is synaesthesia from internally-generated stimuli possible? *Cognition*, 109(1), 143–51. doi:10.1016/j.cognition.2008.08.007
- Spiller, M. J., Jonas, C. N., Simner, J., & Jansari, A. (2015). Beyond visual imagery: How modality-specific is enhanced mental imagery in synesthesia? *Consciousness and Cognition*, 31, 73–85. doi:10.1016/j.concog.2014.10.010
- Stam, H. J., & Spanos, N. P. (1980). Experimental designs, expectancy effects, and hypnotic analgesia. *Journal of Abnormal Psychology*, 89(6), 751–62.
- Stein, T., Hebart, M. N., & Sterzer, P. (2011). Breaking Continuous Flash Suppression: A New Measure of Unconscious Processing during Interocular Suppression? *Frontiers in Human Neuroscience*, 5(December), 167. doi:10.3389/fnhum.2011.00167
- Terhune, D. B., & Cardeña, E. (2010). Differential patterns of spontaneous experiential response to a hypnotic induction: a latent profile analysis. *Consciousness and Cognition*, 19(4), 1140–50. doi:10.1016/j.concog.2010.03.006
- Terhune, D. B., Cardeña, E., & Lindgren, M. (2010). Disruption of synaesthesia by posthypnotic suggestion: an ERP study. *Neuropsychologia*, 48(11), 3360–4. doi:10.1016/j.neuropsychologia.2010.07.004
- Terhune, D. B., Cardeña, E., & Lindgren, M. (2011). Differential frontal-parietal phase synchrony during hypnosis as a function of hypnotic suggestibility. *Psychophysiology*, 48(10), 1444–7. doi:10.1111/j.1469-8986.2011.01211.x
- Tobis, I. P., & Kihlstrom, J. F. (2010). Allocation of attentional resources in posthypnotic suggestion. *The International Journal of Clinical and Experimental Hypnosis*, 58(4), 367–82. doi:10.1080/00207144.2010.499330
- Tomson, S. N., Avidan, N., Lee, K., Sarma, A. K., Tushe, R., Milewicz, D. M., ... Eagleman, D. M. (2011). The genetics of colored sequence synesthesia: suggestive evidence of linkage to 16q and genetic heterogeneity for the condition. *Behavioural Brain Research*, 223(1), 48–52. doi:10.1016/j.bbr.2011.03.071
- Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature Neuroscience*, 8(8), 1096–101. doi:10.1038/nn1500
- Van Leeuwen, T. M., den Ouden, H. E. M., & Hagoort, P. (2011). Effective connectivity determines the nature of subjective experience in grapheme-color synesthesia. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 31(27), 9879–84. doi:10.1523/JNEUROSCI.0569-11.2011
- Wagstaff, G. (2014). On the Centrality of the Concept of an Altered State to Definitions of Hypnosis. *The Journal of Mind–Body Regulation*, 2(2), 90–108.

- Ward, J., Huckstep, B., & Tsakanikos, E. (2006). Sound-colour synaesthesia: To what extent does it use cross-modal mechanisms common to us all? *Cortex*, 42, 264–280.
- Ward, J., Jonas, C., Dienes, Z., & Seth, A. (2010). Grapheme-colour synaesthesia improves detection of embedded shapes, but without pre-attentive “pop-out” of synaesthetic colour. *Proceedings. Biological Sciences / The Royal Society*, 277(1684), 1021–6. doi:10.1098/rspb.2009.1765
- Ward, J., Li, R., Salih, S., & Sagiv, N. (2007). Varieties of grapheme-colour synaesthesia: a new theory of phenomenological and behavioural differences. *Consciousness and Cognition*, 16(4), 913–31. doi:10.1016/j.concog.2006.09.012
- Ward, J., & Mattingley, J. (2006). Synaesthesia: an overview of contemporary findings and controversies. *Cortex*, 42(2), 129–136.
- Ward, J., & Simner, J. (2003). Lexical-gustatory synaesthesia: linguistic and conceptual factors. *Cognition*, 89(3), 237–261. doi:10.1016/S0010-0277(03)00122-7
- Ward, J., & Wright, T. (2012). Sensory substitution as an artificially acquired synaesthesia. *Neuroscience and Biobehavioral Reviews*. doi:10.1016/j.neubiorev.2012.07.007
- Weiss, P. H., & Fink, G. R. (2009). Grapheme-colour synaesthetes show increased grey matter volumes of parietal and fusiform cortex. *Brain : A Journal of Neurology*, 132(Pt 1), 65–70. doi:10.1093/brain/awn304
- Willander, J., & Baraldi, S. (2010). Development of a new Clarity of Auditory Imagery Scale. *Behavior Research Methods*, 42(3), 785–90. doi:10.3758/BRM.42.3.785
- Wolfe, J. M. (1994). Guided Search 2.0 A revised model of visual search, 1(2), 202–238.
- Woody, E. Z., & Bowers, K. S. (1994). A frontal assault on dissociated control. In S. J. Lynn & J. W. Rhue (Eds.), *Dissociation: Clinical and theoretical perspectives*. (pp. 52–79). New York, NY, US: Guilford Press.
- Wright, D., & Loftus, E. (1999). Measuring dissociation: Comparison of alternative forms of the dissociative experiences scale. *American Journal of Psychology*.
- Wyzenbeek, M., & Bryant, R. a. (2012). The cognitive demands of hypnotic response. *The International Journal of Clinical and Experimental Hypnosis*, 60(1), 67–80. doi:10.1080/00207144.2011.622197
- Yang, Y.-H., & Yeh, S.-L. (2011). Accessing the meaning of invisible words. *Consciousness and Cognition*, 20(2), 223–33. doi:10.1016/j.concog.2010.07.005
- Zhou, W., Jiang, Y., He, S., & Chen, D. (2010). Olfaction modulates visual perception in binocular rivalry. *Current Biology : CB*, 20(15), 1356–8. doi:10.1016/j.cub.2010.05.059

